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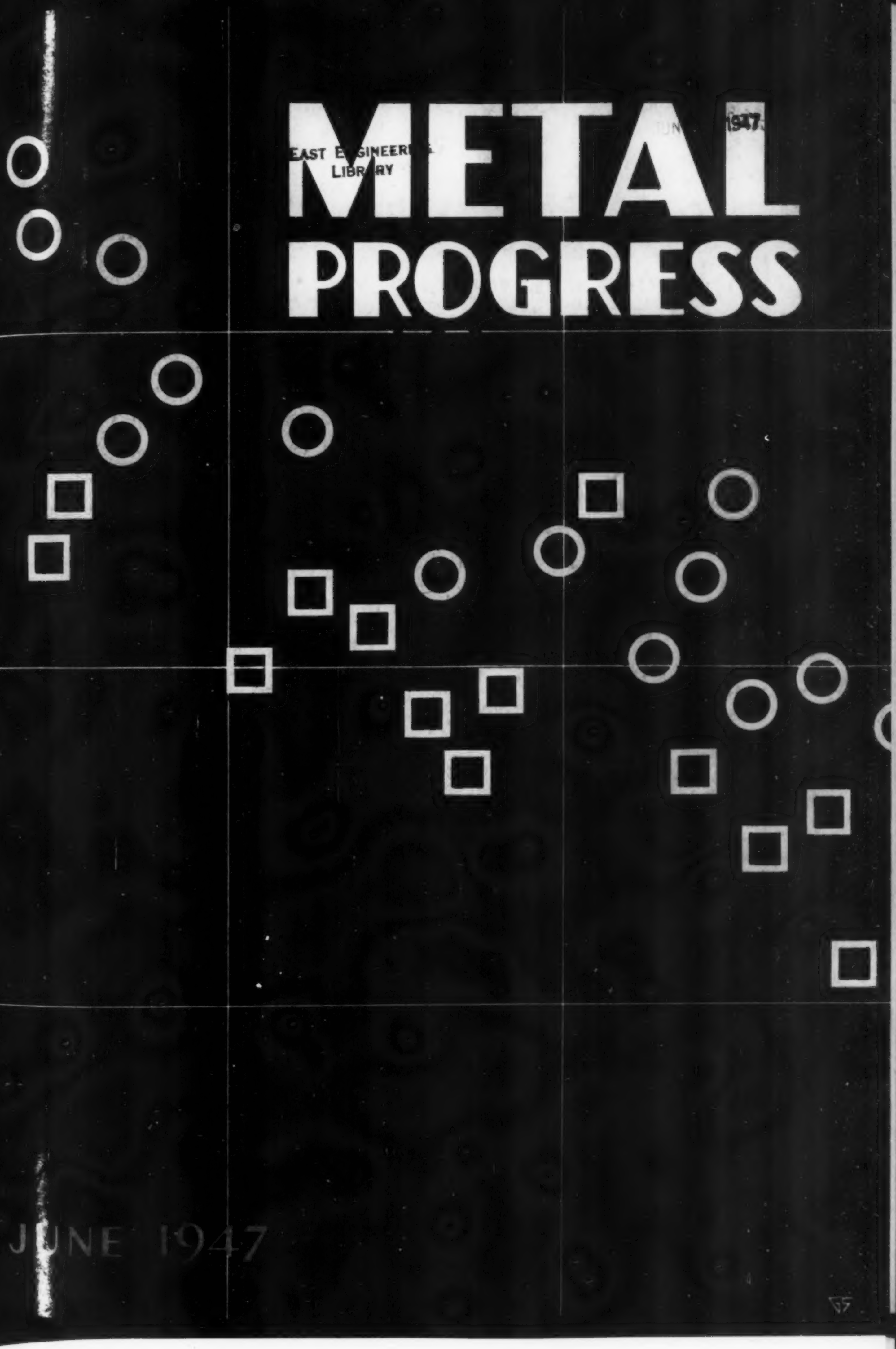

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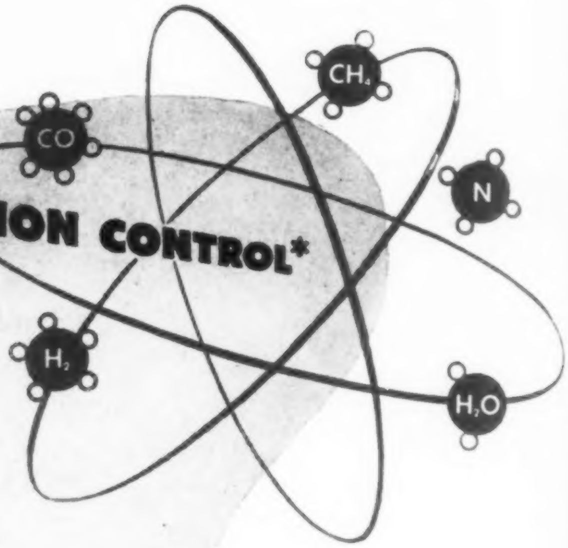

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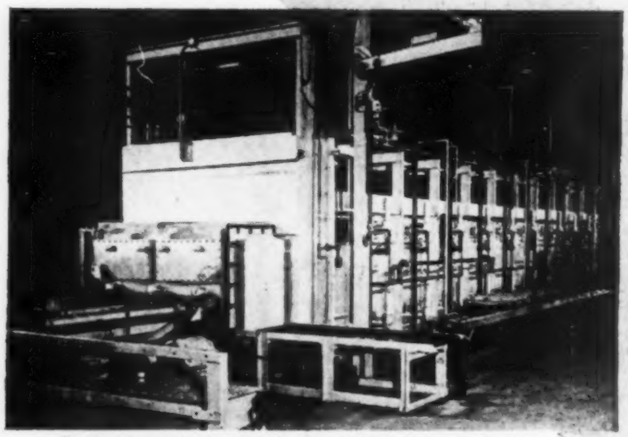

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ERNEST E. THUM, Editor

JUNE, 1947

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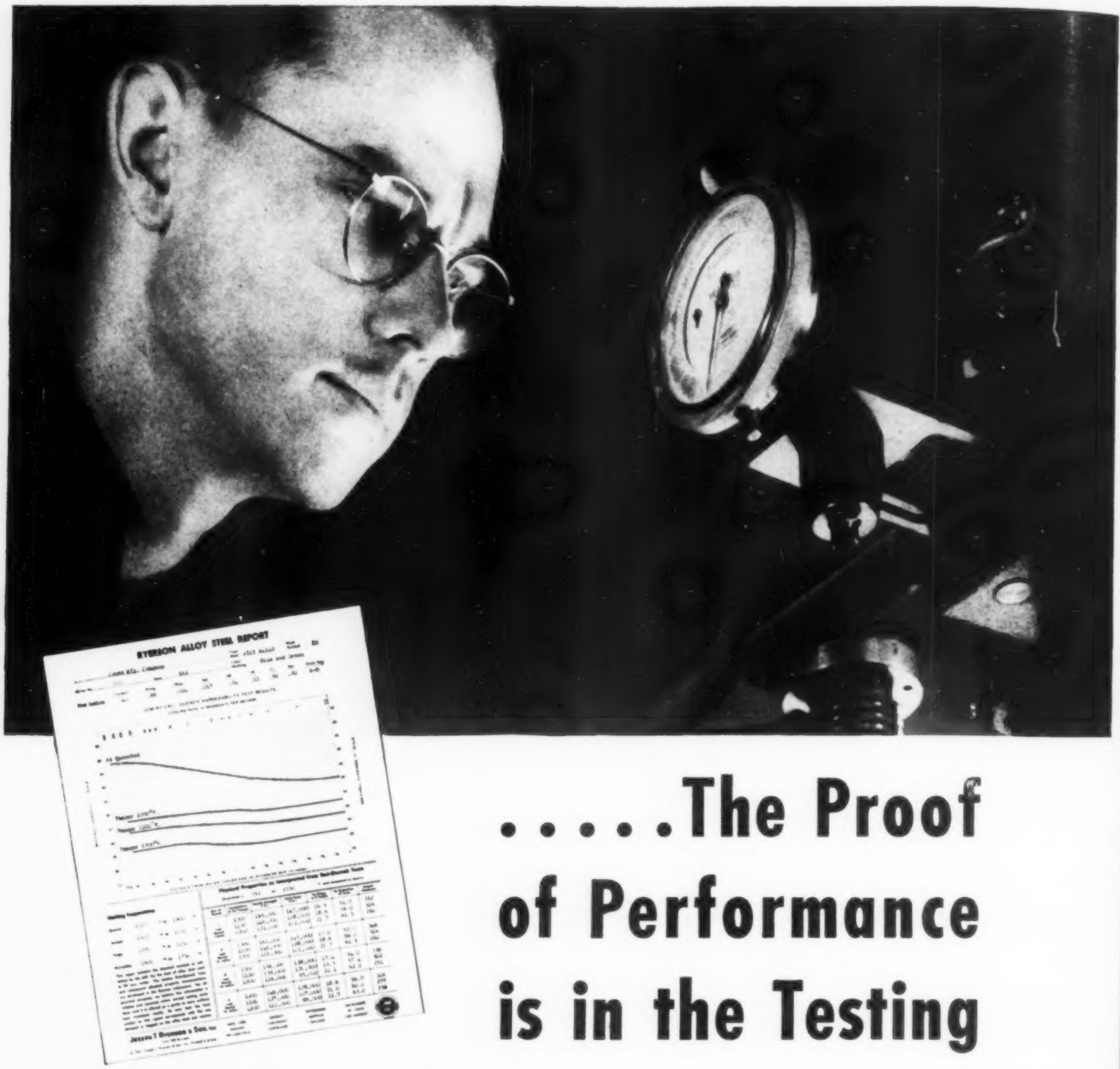

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RYERSON STEEL

This paper is the first report from the research program on the fundamentals of corrosion sponsored by the Office of Naval Research at The Ohio State University. It shows that a passivated surface of low-carbon 18-8 becomes active after exposure to vacuum, and again becomes passive by exposure to air, the action thus being reversible. Electron diffraction shows no indication of oxide layers on passivated surfaces. The authors conclude that a physically adsorbed layer of weakly held gas molecules is responsible.

NATURE AND MECHANISM OF PASSIVITY OF 18-8S STAINLESS STEEL[1]

By M. G. FONTANA[2] and F. H. BECK[3]
The Ohio State University, Columbus, Ohio

THE EXCELLENT corrosion resistance of the stainless steels is usually attributed to "passivation" of the surfaces of these materials. A "passive" surface is one that exhibits "noble" characteristics or practical immunity to attack by corrosive environments as compared to the substantial corrosion that occurs on an "active" surface. In other words, a passive alloy shows much better corrosion resistance than the electromotive series positions of the constituent elements would indicate. For example, the position of chromium in the emf. series indicates poor corrosion resistance, yet chromium is the major element contributing to the corrosion resistant properties of the stainless steels.

Several explanations have been advanced concerning the nature and mechanism of passivity of stainless steels. (It should be emphasized that passivation is a relative term — an alloy may be passive to one environment, but it may be violently reactive to another corrosive medium.) The most widely accepted theory postulates the formation of an oxide, such as chromium oxide, on the surface of the metal and the protection of the metal by this oxide from corrosion. Another theory assumes that chemically adsorbed oxygen forms a protective layer on the metal surface. However, little or no proof has been found to substantiate and, accordingly, to promote the definite acceptance of these theories.

Physically Adsorbed Gas — The research on which this paper is based indicates that 18-8S stainless steel[4] becomes passive because of a physically adsorbed gas. At room temperatures, specimens of this alloy display passivity upon exposure to air and lose passivity upon exposure to reduced pressure (vacuum). This process is reversible in that the alloy can be passivated, broken down, repassivated, broken down, and so on, by alternate exposure to air, vacuum, air, vacuum . . . . . The ready breakdown of the passivity under vacuum at room temperature indicates weak bonds between the gas and the metal which, in turn, indicates physical adsorption. Oxides or chemisorbed gases would be considerably harder to remove or break down and this

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[1] The work reported in this paper was carried out at the Engineering Experiment Station under Contract N6ori-17 Task Order II between the Office of Naval Research and The Ohio State University Research Foundation.

[2] Professor of Metallurgical Research and Director of Corrosion Research Laboratory, The Ohio State University.

[3] Graduate Student and Research Associate, The Ohio State University Research Foundation.

[4] A.I.S.I. Type 304 or S.A.E. 30905; composition: 18 to 20% Cr, 8 to 11% Ni, 0.08% max. C, 2% max. Mn, 1% max. Si.

would probably require an elevated temperature.

This paper includes no attempt to explain the many "peculiar" behaviors of stainless steels in actual service or in corrosion investigations. Our remarks apply directly to the corrosion media studied. One of the purposes of this paper is to report the results of our work in the hope that research by other investigators in this field will be encouraged and stimulated. This study is being continued here and much work remains to be done on the problem.

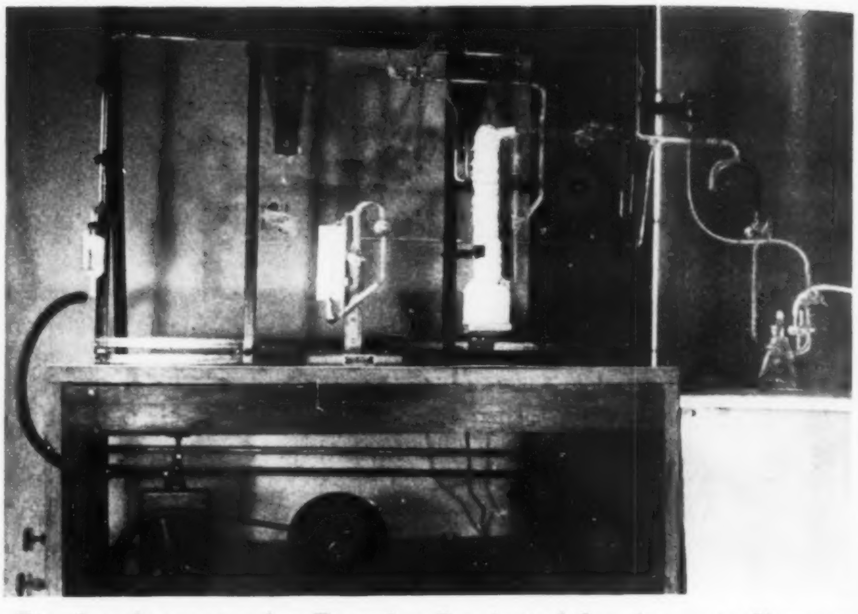

Fig. 1 — Apparatus for Exposing Passivated Specimens to Vacuum

Treatments and Tests

Several passivation treatments were tried during the preliminary phases of this study. The treatment found most effective, based on corrosion tests, is the one which we shall designate in this paper as the "sulphuric-air" treatment. It consists of exposing a specimen of 18-8S to boiling 10% sulphuric acid for 3 min., washing thoroughly in water, and then exposing the specimen to air. Removal by corrosion of a small amount of metal from the alloy, followed by exposure to air, was found to be an effective passivation treatment by one of the authors several years ago. (Incidentally, this situation accounts for many of the apparent inconsistencies in the data resulting from corrosion tests on stainless steels and stainless alloys in sulphuric acid and some other media, as discussed below.)

We arbitrarily prefer to regard the "air-passivation" as the true passivation of stainless steel. This alloy can be protected from corrosion by the formation of surface coatings such as corrosion products, by inhibitors in the corroding medium, and — to take an extreme case — by painting.

Specimens treated in the preferred manner and so passivated are then tested for corrosion resistance by complete immersion in 10% sulphuric acid and in synthetic ocean water at 50° C. (122° F.). The synthetic ocean water is prepared according to the directions given in Naval Research Laboratory Report P-2909 by T. P. May and C. E. Black. Sulphuric acid is selected because it rapidly corrodes an active specimen and is practically harmless if the specimen is passive. In other words, this test is a good yardstick to determine in a short time the performance of the specimen. Another reason for the selection of these media is that the acid results in uniform corrosion or general attack, and the sea water results in the localized or pitting form of corrosion.

In order to clarify the procedures used, we would like to emphasize that sulphuric acid is used to treat the specimen *prior* to exposure to air (passivation), and also to determine the corro-

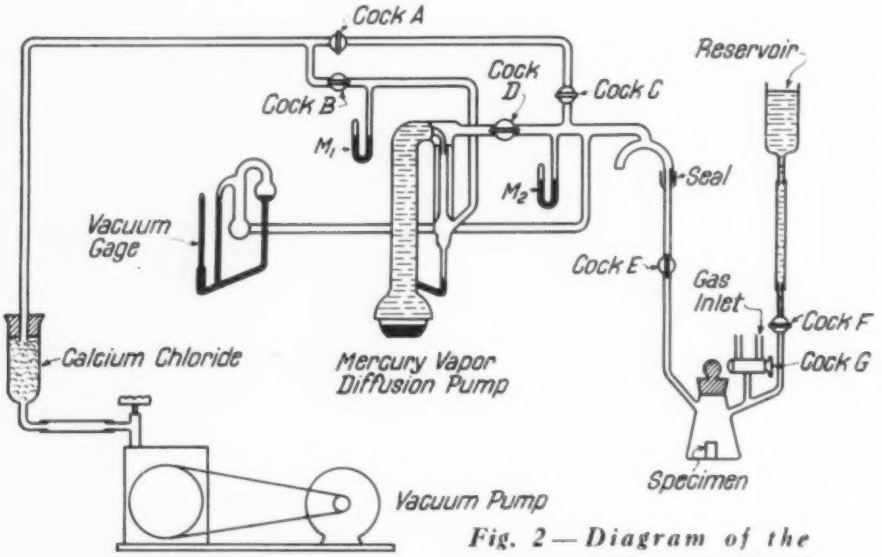

Fig. 2 — Diagram of the Apparatus Shown in Fig. 1

sion resistance of the 18-8S after passivation.

Several sources of supply of Type 304 stainless steel were used during this investigation. Most of the work, however, was carried out on ¼x2-in. bar stock with the following composition: 0.05% C, 18.86% Cr, 9.08% Ni, 0.05% Mo, 0.35% Si, 1.12% Mn, 0.024% S, and 0.016% P.

Test Schedule — A photograph of the vacuum breakdown apparatus is shown in Fig. 1 and a schematic diagram in Fig. 2. (Since the results of the work indicate a promising field for further research, improved equipment is now being assembled, including a more sensitive McCleod gage, a mercury diffusion pump with higher capacity, and a better vacuum pump for the exhaust from the mercury pump.)

The procedure in the tests already made is briefly as follows:

1. Fill the acid reservoir and tube to and including stopcock *F* (see Fig. 2) with 10% sulphuric acid; clean the tubing below *F* with acetone, and also the specimen flask, and dry thoroughly.
2. Seal the specimen flask to the vacuum system with a cement.
3. Evacuate the system to stopcock *E*.
4. Place the passivated specimen in the flask, insert ground glass stopper and evacuate. The system from the diffusion pump to *F* is now under high vacuum.
5. At the end of the vacuum period close *E* and open *F*, thus bleeding in acid to cover the specimen without exposure to air.
6. Open *G* to atmosphere, break vacuum seal by heating cement (joint previously brought up to atmospheric pressure through *A* and *C*), and transfer the flask containing the specimen to the constant temperature bath for corrosion test.
7. For repassivation or exposure to air, argon or other gases, close *E* and open *G* after the end of the vacuum period.

Numerous control specimens were run in this equipment. In these trials, the specimens were handled in exactly the same manner except that the flask was not evacuated (or it was evacuated for only a brief period). In all of them the specimens remained passive.

Time of Exposure to Air

A series of runs determined the effect of the time the specimens were exposed to air on passivation. Specimens treated in hot sulphuric acid, washed and weighed in 10% sulphuric acid and then transferred to the corrosion test without exposure to air remained active. Specimens exposed to air for only a few minutes showed passive characteristics. Since passive specimens lose very little weight (approximately within the accuracy of the weighing technique), the data are not suitable for plotting the time of exposure to air versus the corrosion rate. There may be differences in the stability or effectiveness of the passivity developed on different specimens, but a reliable method for determining these differences has not yet been developed; the break-through

Table I — Vacuum Breakdown of Passivation
(Passivation treatment: Boiling 10% H_2SO_4 for 3 min., washed and then exposed to air.)

SPECIMEN DESIGNATION	PRESSURE, MM. HG.	TIME UNDER VACUUM, HR.	BEHAVIOR IN CORROSION TEST*		REMARKS
			SURFACE	CORROSION RATE MILS PER YEAR	
1 (many)	None	None	Passive	0	
2	0.001	1.5	Active	278	
3	0.001	6.0	Active	280	
4	0.002	1.8	Passive	0	
5	0.002	2.0	Passive	0	
6	0.002	3.2	Passive	0	
7	0.002	4.5	Active	N.D.†	Corrosion started immediately
8	0.002	6.3	Active	N.D.	Corrosion started immediately
9	0.002	7.0	Active	N.D.	Corrosion started immediately
10	0.002	18.0	Active	N.D.	Corrosion started immediately
11	0.002	24.0	Active	N.D.	Corrosion started immediately
12	0.06	6	Passive	0	
13	0.13	75	Borderline	N.D.	Broke down slowly, then corroded
14	0.2	24	Passive	N.D.	

*10% H_2SO_4 at 50° C.

†Not determined.

Table II — Results of Cyclic Tests
(Specimens exposed to air after breakdown of passivation by vacuum treatment.)

SPECIMEN DESIGNATION	VACUUM TREATMENT		TIME EXPOSED TO AIR AFTER VACUUM TREATMENT	SURFACE
	PRESSURE, MM. HG.	TIME, HR.		
C-1	< 0.0005	6	1 hr.	Passive
C-2	0.001	6	5 min.	Passive
C-3	0.001	6	30 min.	Passive
C-4†	< 0.0005	50	30 min.	Passive
C-5†	< 0.0005	50	30 min.	*
C-5*a*	< 0.0005	6	None	Active

*Not subjected to corrosion test but continued as Run No. 5*a*.

†No. 4 and 5 run simultaneously. No. 4 removed and tested for corrosion resistance, but No. 5 again broken down by vacuum treatment (see 5*a*).

potential apparatus may be suitable for this purpose. Attempts are also being made to determine the exact time at which the passivity breaks down during the corrosion tests, since this period could be used to differentiate the stability of various surfaces.

The specimens subjected to vacuum treatments were all passivated by exposing to air for 30 min. or 1 hr. The above tests indicate that these times are sufficiently long to insure the development of a passive surface.

Practically all of the corrosion tests reported herein consist of one 48-hr. period. Results obtained on subsequent periods are of little value since the first period of the corrosion test is similar to the passivation treatment used. In other words, if corrosion occurs during the first period, the specimens tend to become passive while exposed to air during washing and weighing to determine the weight-loss for the first period. Anyone with experience in the corrosion testing of stainless alloys in sulphuric acid is probably familiar with this phenomenon and the supposedly erratic results often obtained.

Effect of Pressure

Table I shows some of the results obtained during this investigation. Specimens 2 and 3 indicate that passivity is destroyed after 1.5 hr. under a pressure of 0.001 mm. Specimens 4 through 11 show that a longer time, or about 4 hr., is required for breakdown at the higher pressure of 0.002 mm. Specimens 12, 13, and 14 also show that the time for breakdown increases as the pressure increases. Perhaps there is a critical pressure above which the passive film would not break down.

Table II gives the results of experiments where the passive film is destroyed by vacuum treatment and then the specimens are again made passive by a subsequent exposure to air. Based on the results in Table I and numerous similar tests, the 6-hr. exposure to vacuum assures breakdown of the passive film.

With a little experience, one can readily tell whether the specimen is active or passive by observing the action on the metal for a few minutes after the acid is bled into the specimen flask. In most runs, however, the specimens are subjected to an actual corrosion test.

Hydrogen in the Metal

One possible objection to the adsorbed gas theory for passivation is that gas (hydrogen) may be removed from the metal while it is in the vacuum, thus rupturing or destroying the passive film. This hypothetical mechanism could be described in the following way:

Hydrogen enters the metal as a result of the boiling 3% sulphuric acid pretreatment. Now assume that a chemisorbed layer or an actual oxide layer is formed on the surface during its exposure to air. When the specimen is exposed to a vacuum the hydrogen is drawn out of the metal and, on its way out, it ruptures the chemisorbed layer or surface oxide and thus destroys passivity. Re-exposure to air then merely heals the ruptured areas by re-forming the chemisorbed layer or oxide.

Table III — Corrosion of 18-8S by Synthetic Ocean Water at 50° C.
(Heavy metals added; pH = 8.2)

SPECIMEN	PASSIVATION TREATMENT	PITS
S-1	None	Many
S-2	Boiling 3% H_2SO_4 3 min.; air ½ hr.	None
S-3	Fuming HNO_3, 1 hr. at room temp.	Many
S-4	30% $HNO_3 + 0.5\%$ $K_2Cr_2O_7$, 1 hr. at 60° C.	Many
S-5	10% $K_2Cr_2O_7$, 1 hr. at 60° C.	Many
S-6	Air at 870° C. for 1 hr.	Large

Runs No. C-4, C-5 and C-5*a* in Table II were designed to check this point. If hydrogen destroys passivity in 1.5 hr. or less at a pressure of 0.001 mm. (see Table I), the hydrogen must have a fairly strong tendency to leave the metal under these conditions. Accordingly, 50 hr. at less than 0.0005-mm. pressure should remove a substantial amount and perhaps all of the hydrogen. Run No. C-4 shows that the surface whose passivity was destroyed by treatment for 50 hr. at less than 0.0005-mm. pressure again becomes passive as a result of exposure to air for 30 min. Assuming that all of the hydrogen in the metal is removed by the 50-hr. treatment, then the repassivated surface should not break down upon subsequent vacuum treatment, if the objection under study is valid. Run C-5*a* in Table II shows that this is not the case because the surface becomes active again during the 6-hr. vacuum exposure.

This experiment is not conclusive, however, since there is no definite assurance that *all* of the hydrogen in the metal is removed by the 50-hr. low pressure treatment. Further work on this aspect is in progress with regard to *(a)* a treatment at elevated temperature and high vacuum to remove hydrogen, *(b)* acid methods, such as electropolishing, to activate the specimens without allowing any hydrogen pick-up, and *(c)* other methods not involving acids for activating the metal surfaces.

Tests in Synthetic Ocean Water

Table III shows the results of tests in synthetic ocean water on 18-8S specimens with different passivation treatments. It will be noted that the sulphuric-air treatment is the only one which prevents pitting of the alloy. In connection with Run No. S-6, it may be of interest to state that numerous corrosion tests were also made in sulphuric acid on 18-8S heated in air at temperatures in the range 225 to 870° C. (430 to 1600° F.) to form oxide coatings. None of these coatings are protective in this acid.

Passivation by Argon

Preliminary tests using cylinder argon gas (nominally 99.8% argon, 0.2% nitrogen) "purified" by passing the gas over hot calcium metal to remove oxygen, and a P_2O_5 tower to remove water vapor, showed that argon passivated 18-8S. "Spectroscopic" argon was obtained later, but gave erratic results as to passivation. If conclusive evidence could be obtained that 18-8S passivates in argon, this information would be very strong and definite support for the physically adsorbed gas theory proposed herein, since this gas is very inert chemically.

All of the argon tests were made on specimens whose surface passivation had previously been broken down by vacuum exposure, except for one attempt to passivate directly with argon after activation in boiling acid. In the last mentioned test passivation was obtained, but the experimental procedure is open to question.

Electron Diffraction—Passivated 18-8S surfaces were extensively investigated in an attempt to find oxides. Electron diffraction patterns gave no evidence of their existence, and these experiments are considered to be indirect evidence that passivity is due, rather, to an adsorbed gas.

18-8S polished with 120 emery paper, following the usual procedure for preparing corrosion test coupons, is not passive to sulphuric acid. Perhaps the cold worked surface due to polishing, or the surface layers formed because of slight heating during polishing, inhibit the formation of an adsorbed gas layer. In addition, removal of the polishing scratches during the boiling sulphuric acid treatment perhaps forms a better base surface for the adsorbed gas layer.

Electron diffraction photographs show an alpha iron pattern on as-polished specimen surfaces, and gamma iron on the surfaces treated in boiling 10% sulphuric acid for 3 min. The small amount of corrosion that occurs during this treatment is sufficient to remove the cold worked metal surface

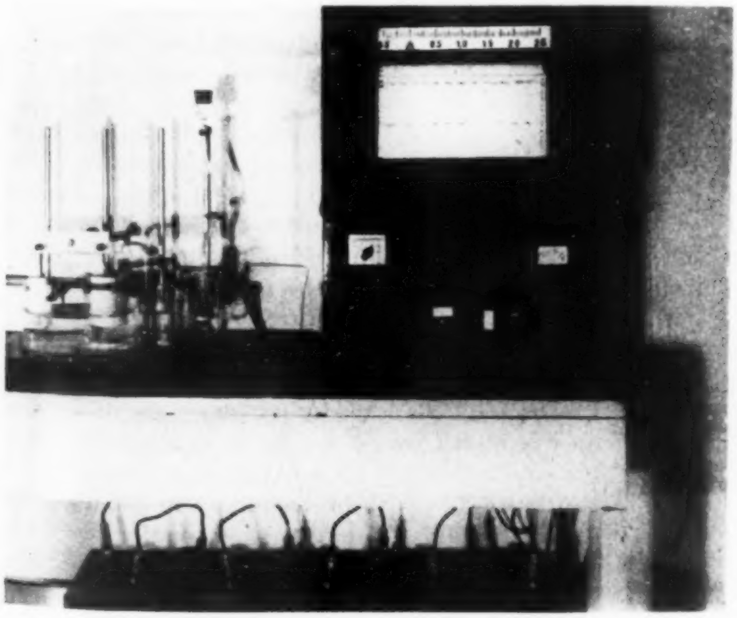

Fig. 3—Break-Through Potential Equipment for Studying Metal Surfaces

layer formed during polishing. There is a good possibility that gamma iron is more capable of adsorbing gas than alpha iron, and this possibility will be further explored through the use of ferritic 18-8 material.

Specimens that were heated in air gave beautiful electron diffraction photographs indicating the presence of crystalline oxides, as expected.

Future Studies

In addition to the studies suggested above, investigations on the effect of other fluids such as nitrogen, oxygen, hydrogen, water vapor, and water on 18-8S and other types of stainless steels are in progress at the Engineering Experiment Station at The Ohio State University.

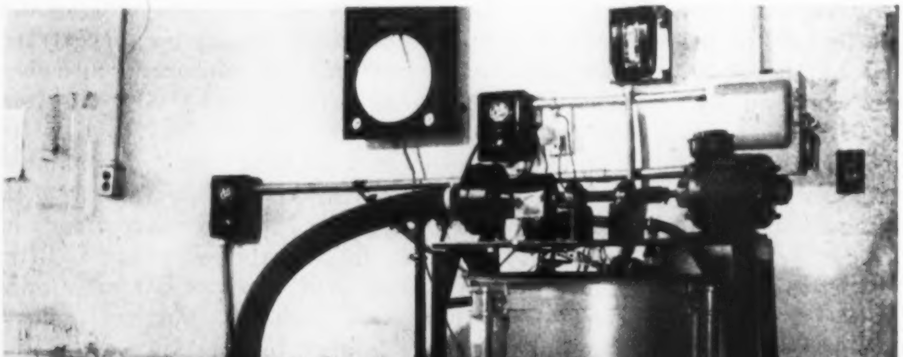

Fig. 4 — Photograph of Equipment for Determining the Erosion-Corrosion Resistance of Materials

The stability of the passive films is also being studied by means of break-through potentials and erosion-corrosion tests, but this work has not progressed sufficiently to warrant discussion. Equipment for these tests is shown in Fig. 3 and 4.

"Passivation" with Nitric Acid

"Passivation" of stainless steel equipment by exposure to warm dilute nitric acid is quite a common practice in industry. Numerous tests here, using this passivation treatment, force the present authors to conclude that this treatment does not passivate stainless steel; it is a fruitless operation and a waste of money as far as passivation benefits are concerned. More and more students of corrosion are adopting this viewpoint. The nitric acid treatment may be of some benefit in removing iron particles that may have been imbedded in the surface of the metal during rolling or other fabrication operations, but this is not a passivation effect; if the metal is pickled after rolling or forming, which is often the procedure, the nitric acid treatment is a superfluous operation. The usual mill operation of pickling should be considerably more effective than the nitric acid treatment by the fabricator or user, as far as passivation is concerned. Pickling doubtless dissolves some of the metal surface and the pickling operation is normally followed by washing and exposure to air. In other words, a pickling operation in the steel mill is somewhat similar to the sulphuric-air passivation treatment used in the work described in this paper.

Adsorbed Gas as the Passivation Medium

The authors believe that this investigation presents strong evidence to support their proposed theory that passivation of 18-8S is due to a *physically* adsorbed gas. This gas is attached to the metal surface by van der Waals' forces, and these forces represent poor adherence or weak bonding. Elementary text books on physical chemistry state that gases held by these forces can be removed by evacuation. On the other hand, *chemically* adsorbed gases cannot be removed by evacuation, according to the literature. Chromium oxide is, of course, a stable compound that does not break down under low pressures at room temperature. Electron diffraction studies show no oxide films on passivated surfaces. Since passivated surfaces become corrodible after exposure to vacuum, it is concluded that the protection is in all likelihood due to a weakly held layer of gas molecules. Many auxiliary problems are worthy of investigation in this connection.

POLISHING METALLOGRAPHIC SPECIMENS WITH DIAMOND DUST

By GORDON C. WOODSIDE and HAROLD H. BLACKETT
Metallographer Senior Technician
Experimental Laboratory, Climax Molybdenum Co. of Michigan, Detroit

METALLOGRAPHIC surfaces must frequently be prepared on extremely hard materials. The conventional methods and standard abrasives may fail to develop the quality of surface desired or require an excessively long time. Faced with this problem, C. M. Loeb, Jr., of our company, suggested that diamond dust be used as an abrasive. Following this suggestion we found that commercial pastes containing diamond dust of the proper particle size were available.

The laboratory of the Climax Molybdenum Co. has employed such diamond dust paste in polishing specimens of hard, friable, molybdenum carbide. The facility with which excellent surfaces could be prepared indicated that this polishing material might be suitable for other materials. It was found that the time of preparation was reduced, nonmetallic inclusions in steels and graphite in gray cast irons were retained, and that flat surfaces were produced, free from relief, even when large particles of hard carbide phases were present in a soft matrix. A short description and discussion of the grinding and polishing technique, using diamond dust pastes, in the preparation of carbide and other specimens follows.

Great care must be taken to prevent breakage and chipping during the initial grinding of hard, friable specimens. The best results have been obtained with specimens mounted in bakelite or similar plastic mounting material. The mounted specimen is held rigidly in a vise on a surface grinder during the grinding operation. A 500-grit, diamond impregnated grinding wheel, 7 in. in diameter and revolving

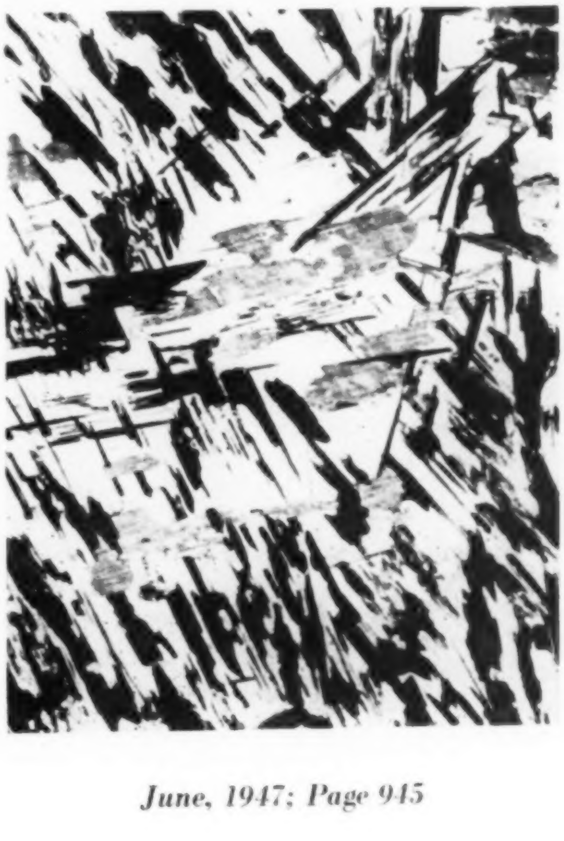

Fig. 1 — Molybdenum Carbide; Vickers Microhardness 1740 to 2122. (First prize in "Miscellaneous Class", metallographic exhibit at 1946 National Metal Congress.) Specimen finished on cloth wheel impregnated with paste of diamond dust, 2 microns max. size. Etched in equal volumes of 10% NaOH and 30% $K_3Fe(CN)_6$. 100 ×

at a speed of 3300 r.p.m., produces satisfactory results. The depth of cut should not exceed 0.0003 in. at any time, and for very friable materials must be held to less than 0.0002 in. for the finishing passes. A total depth of 0.005 in. should be removed. The use of a coolant is advised in this preliminary grinding.

After grinding, the specimen is thoroughly washed to remove *all* the loose particles. The second step consists in polishing the specimen on a conventional metallographic polishing wheel. The wheel is covered with cloth* which has been well impregnated with a diamond dust paste† (powder size, 2 microns, max.). Carbon tetrachloride in small quantities is employed as a lubricant; its use produces a clean surface and prevents sticking on the wheel during polishing. Not more than 5 min. are required for the majority of specimens.

Fig. 2, 3, 4 — Samples of Vacuum Arc-Cast Molybdenum, Vickers Hardness 200. 70 ×

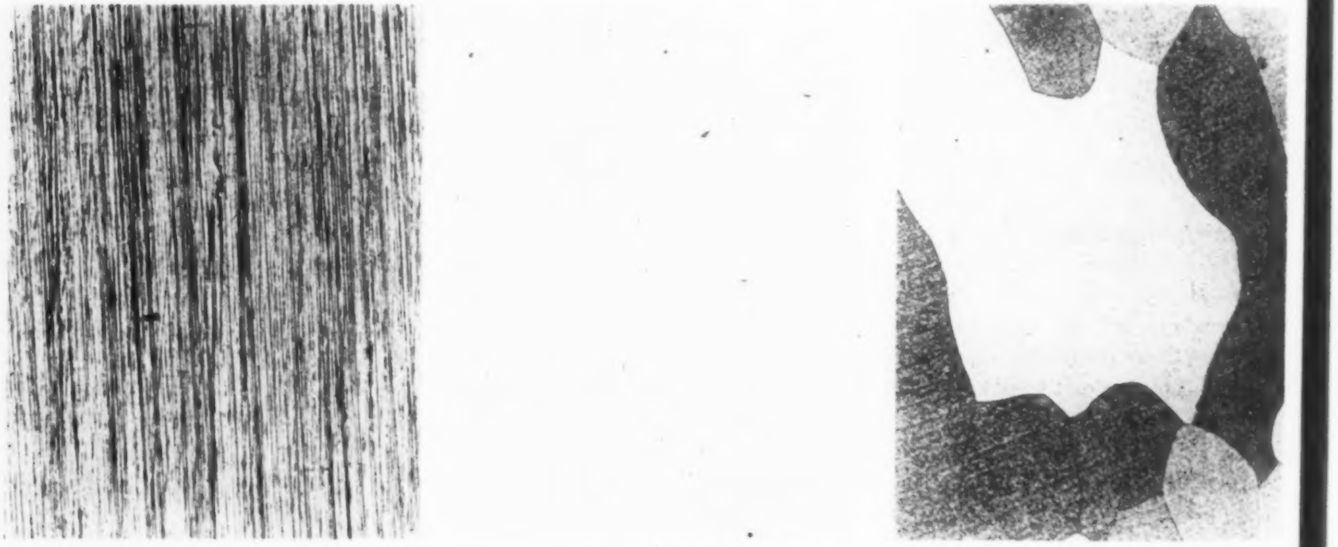

Fig. 2 — After Polishing on 000 Emery Paper; Unetched

Fig. 3 — After Polishing on Cloth Wheel Impregnated With Diamond Dust; Unetched

Fig. 4 — Fig. 3 After Etching in Equal Volumes of 10% NaOH and 30% $K_3Fe(CN)_6$

For most examinations, no further polishing is required. Figure 1 is a photomicrograph of a sample of molybdenum carbide prepared in this manner. The microhardness of this sample was 1740 to 2122 as measured by the Vickers diamond pyramid penetrator.

Large Areas Rapidly Polished

Diamond dust paste enables us to polish larger surfaces in a short time. For example, it is often desirable to examine metallographically the hardness flats on the end-quench hardenability specimens. To do this the specimen is cut into two equal lengths and the hardness flat, already ground to a fine finish for hardness impressions, is polished on the emery papers and then on the diamond dust wheel. Such an examination permits the investigator to evaluate the austenitic grain size, locate the first 1% of extra-martensitic constituent, and correlate microstructures with hardness values as the cooling rate decreases along the length of the test bar. The facility with which these flats can be polished by the new method has greatly increased the use of the end-quench specimen as a research tool.

Figures 2, 3, and 4 illustrate the use of the diamond dust paste on a sample of vacuum arc-cast molybdenum, the correct polishing of which is a tedious operation when standard techniques are employed.

High speed steel specimens may also be polished with greater facility when the diamond dust paste is used. One method uses a lead lap with 280-grit aluminum oxide immediately after grinding, then finishing on the diamond dust cloth wheel. A second method which has been satisfactory consists in using polishing papers No. 320A, 360A, 400A, in succession after surface grinding.‡ Final polishing is accomplished on the diamond dust paste wheel.

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*The authors used Miracloth (Buehler, Chicago).

†The authors used Hyprez Diamond Compound No. 1-W-47 (Engis Equipment Co., Chicago).

‡The authors used Durite (Behr-Manning, Troy, N. Y.).

Preparation of first-class metallographic specimens of gray cast iron requires considerable skill on the part of the metallographer. The graphite flakes must not be pulled out, nor must the space occupied by the flakes be enlarged by rounding off the edge of the surrounding metal. The apparent size of the flakes must not be reduced by flowing metal into the space occupied by them. It is desirable to use an abrasive which has a sharp, clean, cutting action with a minimum tendency to cold work (or burnish, or flow) the metal surface. Diamond dust paste possesses these characteristics.

Figure 5 illustrates such a specimen. The sample was first ground with an aluminum oxide wheel (A36M5V) to produce a flat surface. Scratches left by this wheel were eliminated by polishing on 180-grit emery cloth, and 00 and 000 emery papers in sequence. Finally the surface was finished with the diamond dust paste on a cloth wheel using carbon tetrachloride as a lubricant. The photomicrograph at 1000 diameters illustrates the sharpness of the boundary of the metal which surrounds the graphite flakes.

Specimens of molybdenum and of steel are prepared in the same sequence of grinding and polishing on emery papers, with final polishing on the cloth wheel impregnated with the diamond dust compound. Occasionally, on soft materials, it is necessary to finish with a finer abrasive than that regularly employed by the authors. Finer diamond dust paste is available at somewhat increased cost, but on all materials except cast iron a few seconds polishing with conventional finishing abrasives has been satisfactory.

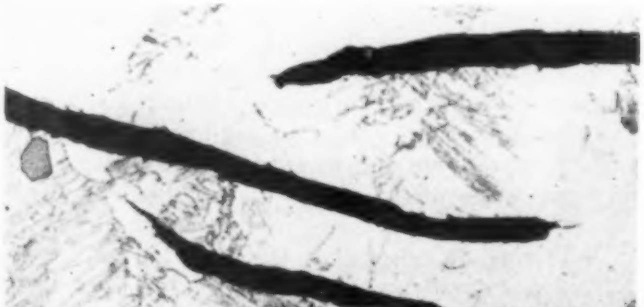

Fig. 5 — Gray Cast Iron, Etched in 2% Nital. 1000 ×. Final polishing with diamond dust; note sharp graphite-metal interfaces. Hardness 156 Brinell

BOOK REVIEW

Ferrous Metallurgical Design (Design Principles for Fully Hardened Steel), by John H. Hollomon and Leonard D. Jaffe. 356 pages, 6x9 in., 140 illustrations. Published by John Wiley & Sons, New York City. Price $5.00.

The subtitle of this book indicates its content better — at least to this reviewer — than the name on the binding. "Design" brings to mind the drawing board. "Planning and Selection", rather, are what this book discusses — how to plan a heat treatment and select a steel (or plan a heat treatment for an available steel) that will perform acceptably in a specific part for a specific duty. While the authors emphasize that all three branches of "design" — dimensioning, purchasing and heat treating — should be interrelated and considered more or less simultaneously, for obvious limitations the book says very little about what used to be called machine design, and its young associate, stress analysis.

During the war the two authors were attached to the laboratory of Watertown Arsenal, and their principal assignment was to cooperate with ordnance designers and contractors by supplying scientific metallurgical information which would help in providing better guns, projectiles and armor. While a staggering amount of literature was available to them about this, that or the other machine part and about the various commercial steels and their heat treatment, they had to systematize much of the information before it became useful to them in this assignment. This book is the result. It marks an important advance on the long road from the practitioner's art (an area known as the heat treater's lore) to the engineer's science (a destination which can be called the metallurgist's generalizations).

While the going is heavy in spots, the mathematical morasses at the end of many enticing by-roads have been avoided. So the perfectionist would say that the book is elementary. In fact it is hardly more than a good and necessary beginning. It is well that the authors are able to continue their labors — witness a recent contribution to *General Electric Review* by Hollomon and Lubahn wherein a start is made toward the analysis of creep (slow plastic flow) of metal at high temperature. Enough is already known about even this complicated phenomenon so that general equations can be written and researches planned to supply missing data about fundamental properties of the metallic crystal. Some day we will "design" an alloy for a high temperature service, rather than grope for it in partially built ternary diagrams and quaternary models.

Two final comments: One is about the price of the book. Five dollars seems a large amount for a 350-page book. However, *The Saturday Review of Literature* warns us to expect the $5 novel in the near future. So we are probably on a new and elevated plateau of bookmaking costs.

Lastly, the book is refutation of the common criticism that American metallurgists are provincial, not paying sufficient attention to British publications. Hollomon and Jaffe make some 326 citations to the literature, as follows: 201 American, 52 British, 46 German, 16 Russian (and the reviewer knows that there is an exceedingly competent Russian translator at the Arsenal). Likewise, the A.S.M. can take a bow — 91 of the citations are to its publications — more than twice the number ascribed to any other engineering or scientific organization.

E. E. T.

CRITICAL POINTS

By THE EDITOR

An ancient shot tower

TRAVELED to Baltimore, the city of MENCKEN and the Merchant's Shot Tower, a city remarkable in many ways, none more than its ability to hold fast to such good things. And so stood in the financial center, alongside a monument commemorating the Battle of North Point in 1814 and the bombardment of Fort Henry, and looked down the hill to a turn in Fayette Street where the old tower still stands erect. While not the oldest in America by any means, it was put up in 1828 and built for the ages, if later experience with tall smelter chimneys means anything. Records show it was one of about 25, scattered along the Atlantic seaboard and in the lead mining regions of the West, operating about the turn of the century. By 1910, however, all the business was in the hands of cartridge makers; the brass or paper shot-gun shell, mass produced, had then entirely supplanted the powder horn and the shot pouch. . . . . The height of this old tower (235 ft.) was truly sky-scraping; massive brick walls, 5½ ft. thick, 45 ft. in diameter at the bottom, lent credibility to old nurses' tales of ghosts, gnomes and goblins waiting in the heavy dank dungeon for bad little Baltimoreans, generation after generation.

Modern manufacture of small round shot

WHILE modern shot towers are tall and square, of structural steel, the manufacturing methods are still the same as in former centuries, the innovations being in mechanical handling of the raw material and the finished product. Tradition has it that the method was discovered centuries ago by a careless workman who was repairing a church steeple's leaden roof (although it is hard to imagine that a man so negligent as to spill a ladle of molten lead would have been so perspicacious as to observe that the splatterings on the ground contained many perfect spheres). Fortunate was he, also, that the lead he spilled contained a modicum of arsenic, else the sweepings would have been all splatterings, no shot! . . . . Most shot today are hardened with antimony — up to 6%, depending on quality desired — to take the blow of the exploding propellant without flattening. Manufacture is simplicity itself. The molten lead is pumped to the top of the tower and overflows into an oversized shallow skillet whose bottom is full of undercut holes about half the diameter of the desired shot. Droplets dripping through assume spherical shape as they fall freely, and are chilled solid by the time they reach a water sump in the cellar. The shot are then dredged out, dried, tumbled with graphite, screened for size, and the out-of-round ones separated by a device that is a miracle of simplicity: A thin stream of shot is spread out along the upper edge of a slightly inclined sheet of plate glass. The out-of-round ones may work toward the edges and drop off, or they fail to pick up enough speed to leap a short gap at the lower edge and start a second journey down the second glass plate. Four such plates, and three such gaps, and the shot arriving at the final jumping-off place are spherical enough! Production of 7 tons of acceptable shot from 10 tons of pig lead is about par.

Why is a shot round?

THIS MATTER of arsenious lead and sphericity is curious. In soft lead about 0.25% arsenic is required to draw a tear drop into a sphere; in hard lead about one-eighth as much arsenic as antimony is added. Some old notes indicate that sodium also has this peculiar influence. Another long lost reference indicates that neither of these elements in small percentages has much influence on the surface tension of the lead. Perhaps they oxidize to a slag of low melting point and high surface tension — but this is pure speculation. Does anyone have any facts that prove or disprove this vision of a metal ball inside a soap bubble of molten oxide?

Hand versus continuous mills for stainless

ENJOYED an afternoon at Eastern Stainless Steel Corp. in Baltimore, accompanied by a staff of experts on stainless sheets which this mill rolls exclusively. It is a fortunate application of an old process. Built by Eastern Rolling Mill as a hand mill for carbon steel sheets shortly after World War I, it had the advantage of latest engineering design of power plant, mills and heating furnaces and — best of all — a roomy building where rearrangements and maneuvering are possible. Hard hit by the depression in the 1930's and the overpowering competition of the new continuous sheet mills, the management reorganized as Eastern Stainless Steel Corp. and confined attention to stainless steel as a specialty where tonnage on each order is still small enough to make hand mills desirable. Likewise there are compensations even when competing in the field of narrow width strip; thus — since the hot rolling temperature range of the high-chromium and chromium-nickel alloys is comparatively high, a *continuous* hot mill cannot go to very thin gages before the ribbon becomes too cool for further reduction. Continuous rolling, therefore, is interspersed with intermediate annealings or else followed by a comparatively large amount of expensive cold rolling. The hand mills, on the other hand, with their convenient furnaces for reheating sheet, can hot roll the sheets or packs down close to required thickness and thus restrict the cold rolling of thin gages to that actually necessary either for temper or finish.

Getting and preserving a smooth surface

SINCE a purchaser of stainless steel sheets nearly always is buying a *surface*, the finishing operations at Eastern Stainless occupy most of the buildings. Notable is a new pickling room, a 40-ft. aisle, 150 ft. long, high ceilinged, crane commanded, entirely lined with stainless sheets. Here is installed the caustic pickling first reported from Rustless Steel Corp. in "Critical Points" in April 1941. Sheets are racked on edge, pins separating sheet from sheet, and immersed 10 min. in molten sodium hydroxide containing 2% of sodium hydride at 800 to 825° F. (The rectangular tank, 20 ft. long by 12 ft. wide by 10 ft. deep, is nickel lined, and the salt melted by immersion gas heaters.) Little of the scale breaks off here, so the caustic bath sludges-up but slowly. After a cold water quench the scale is pervious to the subsequent normal operations — 2 min. in 10% sulphuric acid, water wash, 10 min. in mixed nitric-hydrofluoric acid, water wash, scrub and dry. The last three operations are performed automatically as the sheets pass on rollers between sprays, revolving brushes, and hot air blasts. . . . . Typical of the intelligence with which specialized problems are tackled, the staff at Eastern Stainless has turned some attention to what might be called the paper nuisance. As is well known, sheets, passing from operation to operation in the finishing department, are interleaved with paper

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to prevent one from scratching another, and so on, clear through to the customer. However, *then* they really come in for abuse. Even though press operators be careful, a drawing die or a spinning tool can easily make ten times as many defects in a highly finished surface as the purchaser would tolerate in the metal delivered by the mill. So — a "liquid envelope" in the form of a plastic sprayed over the entire sheet and dried by infrared rays. This coating is critical; it must stick tight enough but not too tight; it must have lubricating properties in the drawing dies; it must be elastic enough to stretch with the metal; it must be strong enough so it can be peeled off when the article or installation is finished. Think of the advantage to a manufacturer, who can then buy a sheet of exactly the right finish, form it, avoid any final polishing, and protect the part through subsequent shipment and erection.

Preventive metallurgy

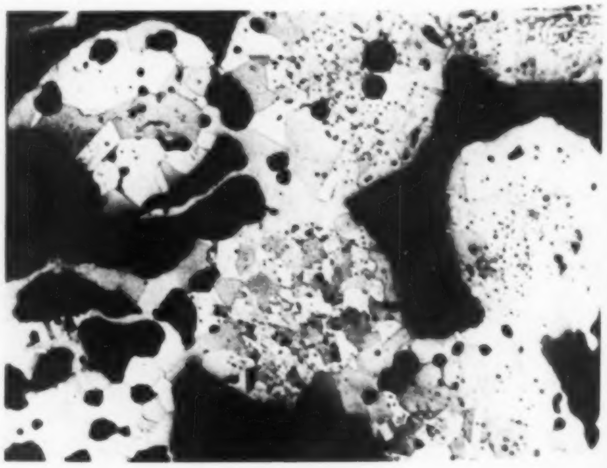
ENROUTE to the Western Metal Exposition, passing through Denver, was glad to revisit RAY MCBRIAN, the Rio Grande Western's engineer of standards and research, and to be stimulated by his stories of how metallurgical methods are continually serving that progressive railroad. Especially interesting was some new information gained by spectrographic analysis of lubricating oil ash — not only of new oil but more especially of samples withdrawn from diesel locomotives or diesel-powered D. & R. G. W. Motorway trucks and busses. New oils under consideration, and each shipment delivered, are burned and the ash analyzed. Harmful abrasive residues from filter clays can thus be detected. But it only begins there. Samples of used oils are ashed and analyzed similarly; comparison with the spectrograms of that oil as it was purchased gives information about troubles already developing in the engines. Prompt action has not only prevented costly service failures but has also improved engine performance generally. For example, if the ash from a sample of oil from a certain engine shows increased intensity in the spectral lines for silicon, magnesium or titanium it indicates that the air filters are not functioning properly. Excessive wear and corrosion of bearings is indicated by increasing amounts of such elements as lead, silver, copper, or cadmium in the ash from the oil. Excessive wear on cylinders and other moving steel parts shows up in the lines for iron, chromium, nickel and aluminum. Many serious troubles have been prevented at the very beginning. . . . . POSTSCRIPT: MCBRIAN has, after many years of agitation, been able to interest the American Railroad Engineering Association in the problem of age-embrittlement of boiler plate, and a proper research program is being financed.

The atomic age

IT SHOULD NOT be necessary to point out that publication of items about nuclear energy and its implications does not imply that the ⊕ has adopted any official "line" concerning this broad subject, nor that THE EDITOR of *Metal Progress* approves of any of the sentiments so printed. In all instances these items, published monthly now for a long time, are verbatim quotations from important statements by politicians, statesmen and scientists of international fame. The quotations are as extensive as space permits, and the necessary shortening has been done with an eye single toward presenting an undistorted image of each author's thought. THE EDITOR's justification is that the development of future uses of nuclear energy is the paramount business of the civilized world. Since the readers of *Metal Progress* form a body of men unusually well fitted to understand and interpret the fundamentals, he believes they should have available as large a number of original documents as possible. If they are well informed, they can make up their own minds, and act accordingly.

Micros from down under

WEEKS — almost months — after the ⊕ Convention in Atlantic City last fall, arrived a small package of micros intended for the metallographic exhibit. They were sent by L. E. SAMUELS, as samples of work "of a reasonable standard of general production" at the Lidcombe branch of the Munitions Supply Laboratories, Lidcombe, New South Wales, Australia. The package suffered unusual transportation delays enroute. One is reproduced herewith to show that fine metallographs — exhibited in great profusion at the National Metal Congress — are by no means the exclusive possession of Americans.



Sintered Bronze Filter. Polished and Etched With Acid Ferric Chloride. 100 ×. (Samuels)

This lecture before the Western Metal Congress reviews the methods of creep testing, the interpretation of the results, and the mechanism of flow and fracture under long continued loads at high temperature. The latter considerations are then used to indicate proper lines of attacking the problem of better service from existing alloys, and devising alloys for extreme conditions.

INTERPRETATION OF CREEP AND STRESS-RUPTURE DATA

By FRANCIS B. FOLEY

Superintendent of Research, The Midvale Co., Philadelphia

THE HISTORY of elevated temperature tests on steels goes back to the latter part of the 19th century at Watertown Arsenal. At that time some tensile specimens were heated by gas and the temperature estimated from the expansion of the specimen. Very active interest in the mechanical properties of metals at elevated temperatures started about 25 years ago, not long after World War I, stimulated by the demands of the steam turbine, the petroleum refineries and the internal combustion engine.

At first was tried the obvious method of testing steels in tension at elevated temperatures in much the same fashion as at room temperature. It soon became apparent that the ordinary methods of determining the elastic properties were quite undependable. The proportional limit was found to be wholly dependent on how accurately one was able to measure the elongation of the specimen undergoing test, the more sensitive and precise the determination, the lower the limit of proportionality appeared to be! This gave rise to the idea commonly expressed — though not unanimously accepted — that, with sufficient precision of measurement, steel would be found to have no real proportional limit and that *some* permanent deformation occurred however light the applied load. (This involved the further postulate — not proven — that a stress-strain curve, if curved, would not return to the origin of coordinates on relief of load.)

Precision of measurement places the limit of proportionality at lower and lower values of stress; increase in temperature of test also lowers its apparent position. Useful determinations of the precise behavior of steel under stress at elevated temperatures therefore required fine measurement and close control and measurement of temperature. The result was that the developments during the 1920's largely consisted of the design and construction of accurate equipment. A notable instance was the Martens-Tuckerman extensometer and auto-collimated telescope, capable of reading elongations to an accuracy of two millionths of an inch. Early experiments with such equipment led to some general ideas as to the shape of the stress-strain curves at temperatures up to 1000° F., but the general state of knowledge by 1924 is indicated by a paper by Prof. F. C. Lea on "The Effect of Low and High Temperatures on Materials", presented to the British Institution of Mechanical Engineers. Lea stated that the most important part of his paper dealt with a phenomenon which appeared to him of "the greatest practical importance, but which", as far as he was aware, "has not been dealt with by any other worker.

"The real problem in connection with metals is to find the stress at which they will continue to deform if the stress is continuously applied — in other words, to find the stress at which they become continuously viscous."

About this time a great deal of precise work was undertaken to study the flow of steel at elevated temperatures under constant load. Tests were carried on for thousands of hours. Accu-

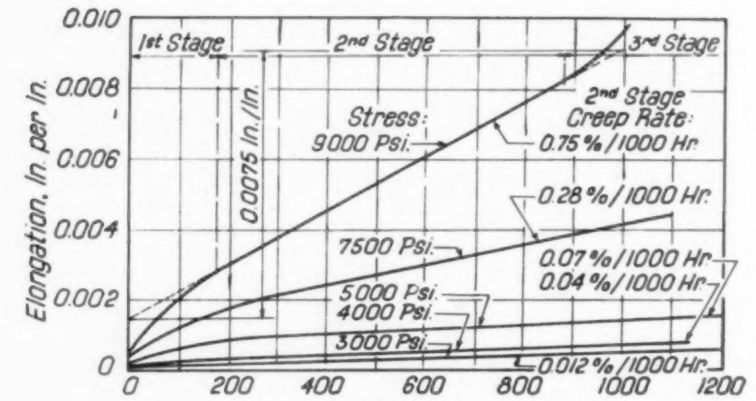


Fig. 1 — Curves Resulting From Plotting Creep Test Data (Cartesian Coordinates) for S.A.E. 1040 Steel, Loaded at Various Stresses at a Constant Temperature of 1000° F.

rately controlled furnaces were designed to give uniformity of temperature along the gage length of the specimen; the specimens were loaded by dead weights hung on the ends of levers. It was necessary to have a large battery of testing units to get data in a reasonable period of time. Reference points on platinum foil were placed at the ends of the gage lengths; observation windows through the furnace walls and a telescope giving a magnification of 20 diameters were used. Later on, the use of two platinum strips fastened to either end of the specimen, each carrying reference marks, enabled observations to be made through a single window near the center of the gage length, and with one setting of the filar eyepiece of the telescope. This was a great improvement for measurements at 1600° F. and upwards. This class of physical measurements came to be known as "creep tests".

Creep test data are obtained after the specimen has been heated to the desired temperature, held there long enough to establish constant and uniform temperature, and then loaded. A zero reading is taken before loading, within a few minutes after load has been applied, and then at desirable intervals thereafter for the duration of the test. Data recorded are time, and elongation in terms of inch per inch of gage length, and when the observations are plotted they give rise to curves of the type idealized in Fig. 1.

Curves such as the top line in Fig. 1 indicate rates of elongation that are referred to as 1st stage, 2nd stage and 3rd stage. In the first stage of creep there is a rapid stretch as the specimen takes up the load initially. The rate of elongation in this first portion of the curve varies with the temperature of test and its duration depends, for a given temperature, on the stress. In any event the initial instantaneous rate falls off and, unless the stress be very high, gives place to second-stage creep, during which the rate becomes constant (or stops — no measurable creep occurs). This second stage of measurable creep may give place to a third stage, during which the creep rate increases and leads ultimately to failure.

It has been suggested that the development of this third stage is caused by the reduction in area, a necessary concomitant of the process of elongation, which in effect causes an increase in the load per unit area. While this is undoubtedly a factor in the transition from a steady rate of elongation to a rapidly increasing rate and ultimate failure, it can be shown that it is not by any means the whole story.

Once the rates of second-stage creep for a number of different loads have been determined and plotted against the loads producing them on log-log coordinates, we find that a straight line expresses the relationship. Such plotting (Fig. 2) enables ready interpolation or extrapolation. Now the *slope* of such a line might be used to describe the resistance to flow, but the figure commonly used is the load producing a creep rate of 0.1% in 1000 hr. (point *A* in Fig. 2). This rate appears to satisfy designers of certain types of heat resistant metals used, for example, in industrial furnace construction and in oil refineries.

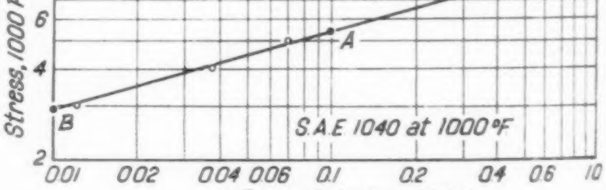


Fig. 2 — Log-Log Plot of Second-Stage Creep Rates at Various Stresses (S.A.E. 1040 Steel at 1000° F.

Turbine rotor designers, however, require much greater resistance to deformation which they would prefer to hold to a rate represented by 0.1% in 10,000 hr. which sometimes is given as 0.01% in 1000 hr. as at point *B* in Fig. 2, and may be — although questionably — translated to mean 1% in 100,000 hr. A creep rate of 0.01% in 1000 hr. is 0.2 millionths of an inch per hour on a 2-in. gage length. Readings taken every day during a creep test would have to be accurate to the order of 5 millionths to be significant.

Creep curves run for the purpose of determining a rate of deformation tell nothing about the *time* it will take for a metal to fracture under the loads applied, and nothing at all about when to expect failure under lower loads. This is one reason why it is inadvisable to assume that a creep rate of 0.01% per 1000 hr. means 0.10% in 10,000 hr., or 1.0% in 100,000 hr. The 9000-psi. curve in Fig. 1 indicates failure in probably less than 1200 hr. (50 days), even though the minimum creep rate (rate in the 2nd stage lasting 700 hr.) is 0.75% per 1000 hr. A test at 9000 psi. on another steel showed a creep rate of 0.6% per 1000 hr. with no strong indication of failure after 16 months, but the same steel carried 40,000-psi. stress at a lower temperature, producing a creep rate of only half as much, although it failed in only half a year.

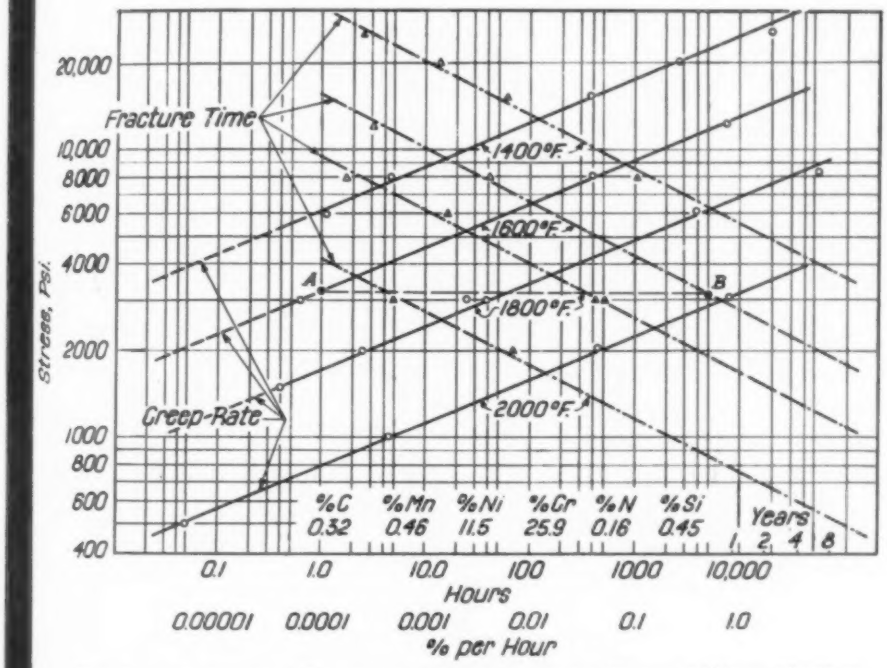


Fig. 3 — Creep and Rupture Characteristics From 1400 to 2000° F. for a Cast Alloy Containing 26% Chromium, 12% Nickel, 0.32% Carbon and 0.16% Nitrogen (Avery, Cook and Fellows)

Fracture time thus becomes of great importance and leads to a somewhat, though not radically, different approach in which the load and temperature are still maintained constant but the test is carried to failure. The time at failure is noted and the incident elongation during the test may or may not be measured. If elongation is measured it becomes possible to plot two sets of data — that is, the creep rate and the stress versus time-to-fracture. The latter is frequently called the "stress-rupture" curve.

Conveniently enough, the plotting of the logarithm of stress against the logarithm of time to produce fracture at a fixed temperature is again a straight line — as it is in a similar plotting of the creep rate against stress. (Perhaps sometime one of our mathematical-physical-metallurgical experts will tell us whether there is any fundamental significance in this straight-line relationship.) Be that as it may, when both the stress-rupture and the 2nd-stage creep rates are plotted together, a diagram such as Fig. 3 by Avery, Cook and Fellows* is obtained. It gives a nearly complete story for a specific material — in this instance a cast 26 Cr, 12 Ni alloy. Note that it is possible to spot, in such a diagram, any particular rate of creep on one of the "creep rate" lines for a particular temperature (actual or interpolated), by following along the horizontal line representing stress to an intersection with the "fracture time" line for the same temperature, and reading off the time when this rate of creep will produce failure.

For example, suppose you are interested in an application of this 26-12 that will operate at 1600° F. As usual, you wish to know the stress that will produce 0.1% creep in 1000 hr. Point *A* represents these specific conditions; the stress is 3225 psi. Following across the horizontal for this stress we reach the "fracture time" line for 1600° F. at point *B*, or 5000 hr., or a little less than 7 months.

Such figures are particularly interesting because they show that loads producing a creep rate of 0.1% in 1000 hr. will break this material within a year. Consequently, while such a creep rate is commonly used to describe the relative creep resistance of metals for a variety of elevated temperature applications, it is useless as a figure for designing equipment for anything but quite limited service. For this reason, careful designers of equipment for a number of applications in high temperature operation are in the habit of arbitrarily using half this value for computing dimensions of load-carrying parts and equipment.

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*"Engineering Properties of Heat-Resistant Alloys", by Howard S. Avery, Earnshaw Cook and J. A. Fellows, *Transactions* of the A.I.M.E., Iron and Steel Division, V. 150 (1942), p. 373.

Fig. 4 — Data From Fig. 4 Replotted to Show Limiting Creep Strengths (L.C.S.), One Half That Value for Design, and Loads for Rupture in Four Years

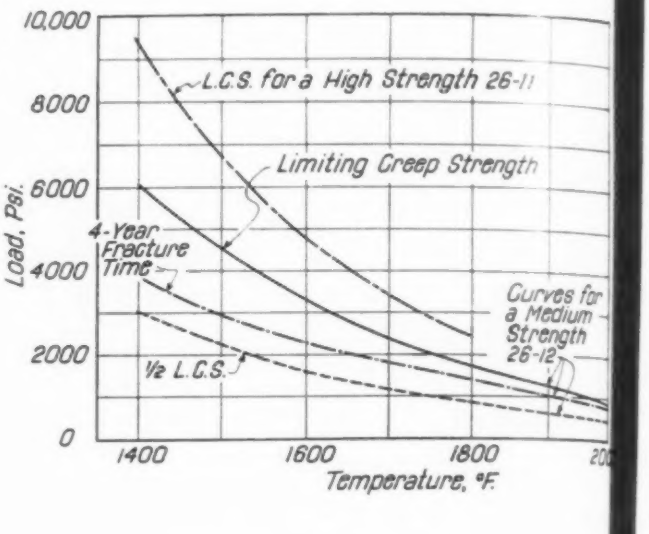
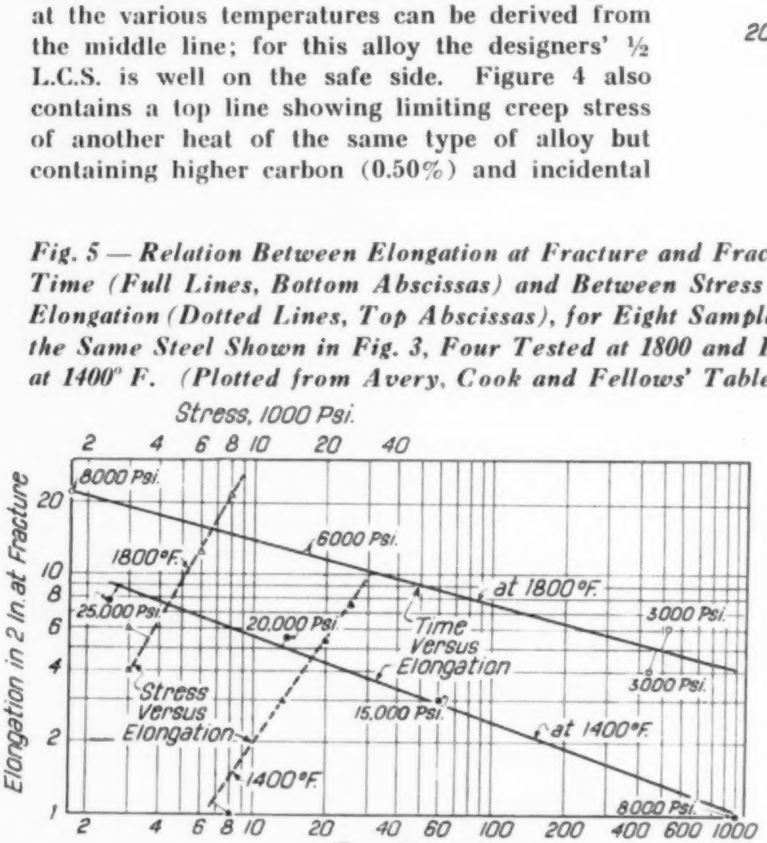


Figure 4 is a replotting of some of this information in Fig. 3. The "limiting creep stress", "L.C.S." — stress for producing a creep rate of 0.1% in 1000 hr. — is shown as the full line (second from top). Half this value is shown as the bottom line. Stress for fracture in four years at the various temperatures can be derived from the middle line; for this alloy the designers' ½ L.C.S. is well on the safe side. Figure 4 also contains a top line showing limiting creep stress of another heat of the same type of alloy but containing higher carbon (0.50%) and incidental elements "balanced" for fully austenitic structure, no sigma phase, no boundary carbides, and a fine carbide dispersion throughout the austenitic matrix. This line is placed on the diagram to emphasize the fact that the other lines represent average conditions for a considerable scatter of observed points.

Fig. 5 — Relation Between Elongation at Fracture and Fracture Time (Full Lines, Bottom Abscissas) and Between Stress and Elongation (Dotted Lines, Top Abscissas), for Eight Samples of the Same Steel Shown in Fig. 3, Four Tested at 1800 and Four at 1400° F. (Plotted from Avery, Cook and Fellows' Table V)



Ductility — If the final elongation of specimens be measured after testing to failure, it is generally observed that as the time to fracture of a given metal at a given temperature is increased, the elongation decreases. It follows, of course, that the elongation also decreases with the load that produces fracture. In short, the rapid deformation produced by overloading causes greater ultimate flow than does the slower deformation resulting from low loads.

When plotted on log-log coordinates the elongation versus stress lines for given temperatures and the elongation versus time relationships both appear as straight lines. Figure 5 plots data for the 25 Cr, 12 Ni alloy heat so carefully investigated by Avery, Cook and Fellows.

Those who are acquainted with failures of this alloy in service state that they rarely occur as a result of creep. How such opinions are arrived at is not clear, unless they associate "creep" with large ductility and necked-down fractures. Were a very long sustained slight overload to produce failure, the fracture would not necessarily show evidence of flow — in other words, there might be so little elongation that it would go entirely unnoticed. If marked deformation were observed it would mean that rapid flow had occurred under considerable overload. Thus, a "deformationless fracture" is not necessarily evidence of failure through inherent brittleness, nor because of some localized imperfection; if it has occurred after loading for a very long period of time the chances are that slight overloading was the cause.

A U.S. patent No. 2,416,515, recently issued to Charles T. Evans for a 19 Cr, 9 Ni type alloy having a number of elements added to it, shows a decreasing order of elongation at fracture with decreasing loads and longer life at 1200, 1350 and 1500° F. Fracture times of 10, 100 and 1000 hr. produced 20, 10 and 5% elongation, respectively, at 1200° F., and 25, 10 and 5% elongation at 1350 and 1500° F. This appears to be characteristic of the behavior of metals.

Data from stress-rupture tests may prove a valuable warning against some arbitrary method of deriving design stresses from the limiting creep stress. This becomes particularly true if metallurgists must build up a high degree of resistance to creep in a given material. The trend is similar to the old one encountered in the room temperature properties of metals, in which high resistance to deformation has been developed, yet it is associated with a degree of brittleness which prevents the development of full strength in tension. This is observed in steels hardened to, say, 650 Brinell but which fail at normal temperature in a brittle manner under hardly more than 200,000 psi.

Table I shows some information on this point derived from four heats of 25 Cr, 12 Ni alloy. Variations in the limiting creep stresses and the extrapolated life expectancies are principally due to the effect of carbon content on the structural stability of the alloy. The data in the table were obtained by carrying the elevated temperature tests to failure, plotting results on log-log coordinates as already described, and then extrapolating. While, for example, it is indicated that 1500 psi. will produce the same order of creep in Alloy D at 1800° F. as 300 psi. would produce in Alloy A, the latter will sustain its load for a very long period of time whereas Alloy D will fail in only two years. Experienced designers take the limiting creep stress of this 25-12 type alloy (0.1% per 1000-hr. creep rate at 1800° F.) to be 1600 psi. and use half this value (800 psi.) for design purposes. Adequate life under such conditions is indicated for Alloys B and C.

Structural Changes

What happens within the metal during stressing at elevated temperatures? What do the various stages of creep indicate?

The first stage of creep is produced by a rather sudden application of the load at the elevated temperature. This load may be sufficient ultimately to break the specimen in a short time, in a very long time or — for practical considerations — not at all. But it is applied *at once* and not, as in a conventional test at room temperature, by small increments. It naturally produces rapidly the phenomena associated with a short-time tensile test. The amount of stretching depends on its modulus of elasticity and its yield point (if any exists at the temperature). Some of the deformation in the first stage of creep is usually permanent. Depending on the load and on the temperature this permanent set or plastic flow may be a large or small portion of the elongation experienced at the time. The fact that there is a certain amount of recovery upon unloading the specimen while still at temperature is indicative of a certain degree of elastic yielding.

When a metal is loaded rapidly at room temperature with stresses above the yield point, distortion takes the form of slipping along crystallographic planes, but below the ultimate stress this distortion simultaneously increases the resistance to slip upon removal of the stress, so that the hardness is increased and the yield point is also found to have been increased if the specimen is reloaded. This phenomenon has long been taken advantage of in the cold drawing of wire, and in autofrettage whereby the strength properties of hollow forgings, such as gun barrels, are improved by what is called cold working.

Much the same effect occurs at elevated testing temperatures. Professor Lea, in his 1924 paper cited at the outset, gives stress-strain curves for repeated tests on nickel-chromium steels at 612 and 932° F. (Fig. 6). It is obvious that comparatively rapid straining, even at these temperatures, fortifies the metal against further strain — raises its elastic limit.

Under the influence of a *slow* rate of deformation (as in creep) and an elevated temperature, such effects of "cold" working and the softening associated with annealing are opposed to each other. Under certain rates of loading at certain temperatures cold working may predominate and prevent or slow up the rate of creep; under other conditions of loading and temperature no effective amount of cold working can prevail and it is not a factor in creep testing.

Generally speaking, the effects of cold working decrease with an increase in temperature, and the temperature limits with respect to cold working effects depend on the composition of the metal. Ferrous metals tend to work harden to such an extent that it is difficult to detect flow under

Table I — Life Expectancy of 25-12 Castings at 1800° F.
(Avery, Cook and Fellows)

ALLOY	COMPOSITION				L.C.S.*	EXPECTED TIME TO FRACTURE		
						AT ½ L.C.S.		AT 800 PSI., YEARS
	C	CR	NI	N		STRESS	YEARS	
A	0.19	26.5	11.4	0.08	600 psi.	300 psi.	570	4
B	0.31	26.5	11.4	0.07	1150	575	217	34
C	0.32	26.1	11.4	0.13	2100	1050	23	114
D	0.45	26.8	11.4	0.08	3000	1500	2	11

*Stress for limiting creep rate of 0.1% per 1000 hr.

constant load at room temperature. On the other hand, some nonferrous metals offer excellent opportunities for the study of flow at ordinary temperatures.

Permanent Deformation

The permanent deformation in the first stage of creep may be shown by the experiment plotted in Fig. 7. Instead of maintaining temperature and load constant, as in a normal creep or stress-rupture test, the load in this test was removed and the temperature allowed to drop to normal at intervals. The process was repeated a number of times and the rate of deformation of the specimen was found to be greatly increased. The serrated line records such cyclic heating and loading. The upper curve marked A represents creep at constant temperature and load. Curve A is repeated at the lower edge of the chart in order to permit easy comparison with the rate obtained by cyclic stressing. A third curve, B, gives the rate obtained when the period during which the specimen was at rest is subtracted from the total time.

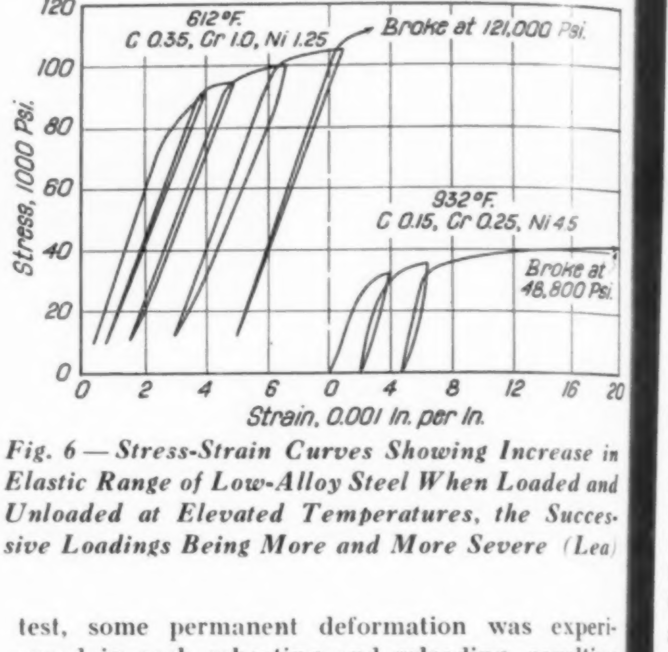


Fig. 6 — Stress-Strain Curves Showing Increase in Elastic Range of Low-Alloy Steel When Loaded and Unloaded at Elevated Temperatures, the Successive Loadings Being More and More Severe (Lea)

It is evident that, under the conditions of this test, some permanent deformation was experienced in each reheating and reloading, resulting in a permanent increase in the length of the specimen at each cycle. This behavior differs from that of the steady creep test conditions, in that under constant load-temperature conditions the first stage of creep was experienced but once and was succeeded by a steady but decreasing rate of flow for the period of 900 hr. (Curve A). Under a series of similar tests using decreasing stresses, the rate of deformation would presumably decrease and ultimately a load might be found at which no permanent deformation — or an unmeasurable amount — would be produced.

This type of test might supplement further the data now being obtained by means of steady creep tests and stress-rupture tests. Unlike cyclic loading at room temperature — which strengthens the metal by cold working it — this type of loading, at temperatures high enough to render "cold work" ineffective, causes an *increased* rate of deformation.

In the second stage of creep, during which a continuous (even if not uniform) rate of creep is maintained, the mechanism of deformation is probably of two types. With the higher rates of second-stage creep, deformation probably occurs by slip in varying magnitude throughout the crystals. Under low loads with a slow rate of deformation it is likely that deformation is confined largely to the neighborhood of the grain boundaries.

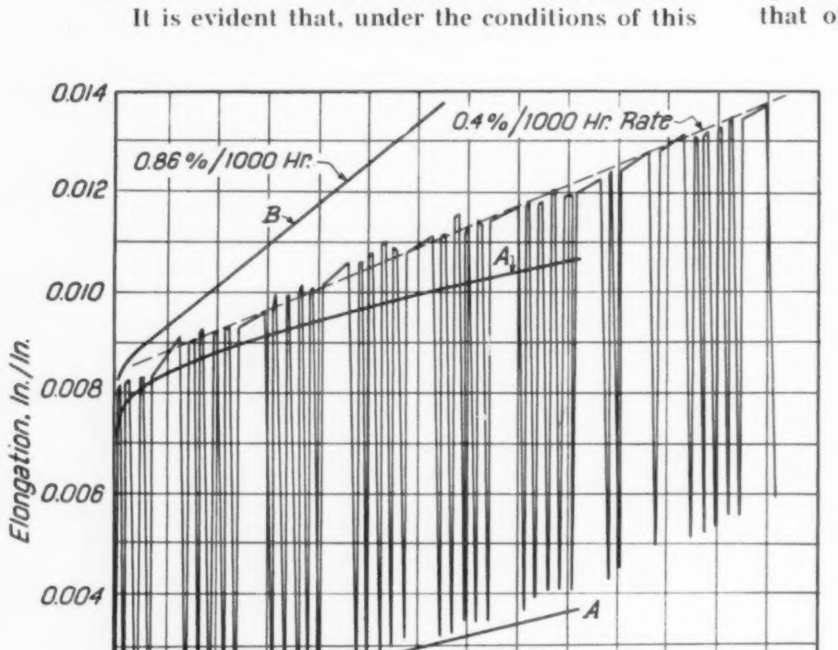
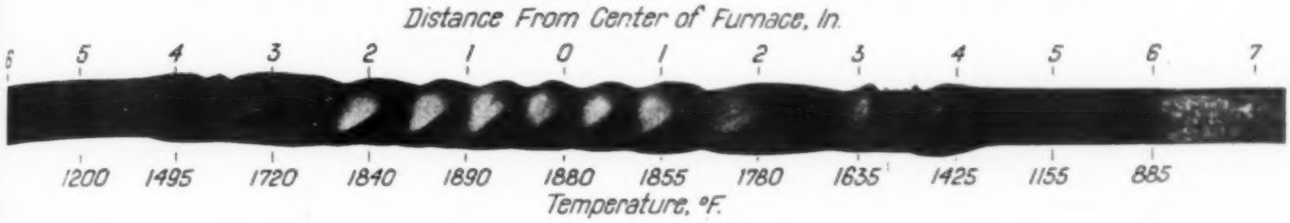


Fig. 7 — Effect of Interrupted Heating and Loading on the Rate of Deformation. Conditions of test: 1500° F.; 6000-psi. stress. Upper Curve A is the creep curve for steady load and temperature. Curve B is summation of elongations in cyclic experiment for the actual time under load

Fig. 8 — Sauveur Twist Experiment on Silcrome (3% Si, 8% Cr) Showing Mobility at Temperatures Corresponding to Transformation



Hanson and Wheeler presented rather strong evidence of this in their interesting studies* of the behavior of polished specimens of aluminum, which were loaded at temperatures at which it was possible to observe microscopically the progress of deformation of the crystal structure. When strained at the rapid rate ordinarily used in tensile testing, numerous slip planes developed throughout the crystals when tested at room temperature and at temperatures up to at least 750° F. However, when strained at 482° F. at the rate of only 4% in 20 min. and then further slowly extended to 21% in 210 hr., deformation appeared to be confined to the neighborhood of the grain boundaries. Slip bands, present abundantly under conditions of rapid straining at the same temperature, were almost if not entirely absent. Under rapid straining, failure ultimately occurred in the normal transcrystalline manner, but under the low rate of straining the fracture was intercrystalline.

Such behavior as this does not support a theoretical equicohesive temperature at which the transcrystalline strength of a metal and its intercrystalline strength are equal; below this "equicohesive temperature", failure occurs by slip within the grain, and above it, failure occurs in the grain boundaries. The two types of failure have been produced by Hanson and Wheeler in aluminum at the same temperature by a change in the rate of strain.

Is Failure Inevitable?

Does all creep testing inevitably end in fracture if carried on long enough?

Can a metal carry a load, however low, at high temperatures (in the realm of flow) indefinitely without fracture?

Extrapolation of stress-rupture data on log-log coordinates suggests that fracture is inevitable.

There is the evidence by Hanson and Wheeler that as stress decreases the deformation of the structure is largely confined to the grain boundaries — as though the low stress were in excess of the intercrystalline cohesive strength of the metal but below that of the crystal planes within the grains.

Failure thus appears to be selective.

The whole question of the usefulness of metals at elevated temperatures involves the kind and degree of movement produced in the crystalline material. Mechanical movement impressed on the structure is aided in its effort to produce deformation by movement within the metal itself — hence the relative ease with which mechanical deformation is accomplished when the constituent atoms making up the crystalline aggregate are set in motion by heat. Another source of atomic movement in crystalline materials is recrystallization and grain growth. Rapid recrystallization is probably a potent weakener of crystalline materials because it brings a multitude of atoms into motion, all bent on assuming a new position in a space lattice. The same is true at temperatures of transformation. The effect of this is readily apparent in the twist tests which Sauveur inaugurated to show resistance of steels to deformation at high temperatures. In his experiments there was a temperature gradient along the bars, and rapid numerous twists piled up at the region corresponding to the temperature of transformation. This is shown in Fig. 8.

Aside from any phase change that may affect movement of the atoms, there is the phenomenon of grain growth itself. This involves grain boundary atoms which are swinging from the orientation or influence of one crystal into that of the neighbor which is undergoing growth. If the common orientation of the atoms within a crystal is thought to produce a field of energy about each crystal which influences the orientation in adjacent crystals, then — for some distance away from the grain boundaries — there would exist a region of disregistry of the atoms relative to the lattice points occupied by atoms unaffected by such extraneous influence. Such regions as these, in the neighborhood of crystal boundaries, would not have the same resistance to mechanical deformation as the relatively fixed region of the crystalline lattice in the middle of the grains. In some particular surface separating the grains from each other would be found the weakest portion.

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*Institute of Metals Lecture, 1939, on "The Creep of Metals".

In other words, there would be a region in the neighborhood of the grain boundaries in which a gradation of resistance to deformation would be found, extending from a maximum well within the grain to a minimum at what may be called for convenience the actual grain boundary. The form of this gradient will depend on the susceptibility of the metal to grain growth at the temperature of stressing.

The grain size may be quite stable or very unstable. For example, the condition existing at grain boundaries of a given metal at 1600° F. will be different if that metal has previously had a coarse grain size conferred upon it by an exposure to, say, 2000° F. than if a fine grain size had been conferred upon it by previous exposure to, say, 1400° F. In the latter event growth will be very active, whereas in the former it will be quite sluggish.

Furthermore, there may be a great difference between the resistance of the body of the crystal to flow and the resistance of the disregistered atoms in the grain-boundary layer. If this difference is large — under a certain set of conditions — ultimate failure is likely to occur with little or no deformation; if both grain material and boundary material have more nearly equal resistance, there will probably be a considerable amount of plastic flow of the piece before fracture occurs.

If, then, the load applied be one which overcomes the resistance of the strongest planes deep seated within the individual crystals the entire structure of the metal is set into motion — slowly when the load is just sufficient, and rapidly if it is greatly in excess. Extensive deformation is likely in either event. Let a load be applied which is just a little *less* than that necessary to overcome resistance of the stable deep-seated planes within the crystal, yet well in excess of that necessary to overcome the weakest resistance in the "grain boundaries", and movement of the metal will occur in the region of the grain boundaries — flow occurs with some elongation which, being localized, is not as great as that produced by over-all deformation of the structure. Finally, if a still lower stress, only sufficient to overcome resistance of the weakest bonds in the "grain boundaries", is applied there is very little deformation and failure occurs after a long period of time through the grain boundaries with little disturbance of the remainder of the structure.

The above mechanism of failure gives rise to the concept of a load which represents the intercrystalline strength of a material and which may be borne indefinitely. It is the load obtained by extrapolation to zero elongation the dotted lines of Fig. 5 representing load to rupture versus elongation.

The above analysis is thought to be fundamental but extremely simplified — probably oversimplified. However oversimplified it may appear, it seems to explain logically the observed strengthening effect of a large grain size, and the decrease in elongation in fracture produced by low loads over long periods of application.

Alloying for High Temperature Service

What part does alloying play in strengthening metals for high temperature service?

It plays the same role at elevated temperatures as at room temperature, with the added factor of affecting resistance to rapid atmospheric attack (ordinarily not a factor at normal temperatures or which can be taken care of readily by protective coatings of various kinds). Chemical reaction between hot gases and the metal, obviously wasting the resisting medium, can be mitigated by proper alloying. Furthermore, gaseous attack at elevated temperatures takes place, at least initially, through grain boundaries; thus it is an added weakening influence leading, as such localized action does, to stress concentration.

With chemistry so devised as to insure a surface of maximum stability, alloying affects strength by creating resistance to deformation and flow at high temperature in three ways:

1. By obstructing slip within the grains through "roughening" of the atomic planes of the crystals or through the setting up of stronger bonds between dissimilar atoms.

2. By the formation of intermetallic compounds which — according to the mode of distribution, whether finely dispersed within the grains of the metal or segregated in grain boundaries — may either strengthen or weaken the structure.

3. By either promoting or retarding grain growth.

To these should probably be added a fourth possibility — that of suppressing or of causing the formation of another allotropic phase.

Certain steps to be avoided are indicated in order to attain highest high temperature strength. They are, *(a)* avoid conditions promoting rapid grain growth, and *(b)* avoid using metal in a range of temperature where it undergoes transformation. One should therefore impose a grain size which is not likely to grow at the temperature of service, and generally follow the practice of rendering the structure as stable as possible prior to putting it into service. Obviously this structure should be stable *at the temperature of service.* ●

CORRESPONDENCE

Wire Cord Tires for Heavy Duty Trucks

Akron, Ohio

To the Readers of Metal Progress:

As a result of developmental tests during the war, the Firestone Tire and Rubber Co. is now in experimental production of heavy-duty pneumatic tires wherein braided steel cords replace the fiber cords in the carcass of the conventional tire. The purpose is to provide a stronger tire for severe service such as logging, quarrying and heavy construction and earth moving.

Patented cold-drawn wire, 0.0058 in. diameter of 375,000-psi. tensile strength and 2% elongation in 10 in., is made from coarse-grained steel containing 0.70% carbon and 0.60% manganese. Three of these tiny wires are first stranded together, then six of these strands are twisted around a central strand of rayon, making a cord containing 18 wires plus a core of rayon. After cleaning, this wire cord is brass plated to provide strong adhesion to rubber.

Wire tires are made the same way as tires reinforced with cotton, rayon, or nylon. The brass plated "rope" is built into a rubber carcass, with a high degree of precision as to spacing. The plies are cut on a bias, and drum-built into regular casings, four plies to a tire. The wire is so fine that two miles of it weighs only a pound, yet one 9.00-20 tire contains 28 lb. or 55 miles.

Each wire cord has a diameter of 0.036 in.; its tensile strength is about 180 lb. A rayon cord of similar diameter has a tensile strength of about 34 lb. The heat generated in a tire while in service decreases the strength of fiber cords but not of wire. The wire tire is operated at about 30% higher inflation pressure than a cotton tire. Because steel conducts heat better than fiber, wire tires run about 25° F. cooler than cotton tires; this is most important because heat destroys rubber. Fibers stretch in service, causing tire growth and increased tread wear; steel wire does not stretch. Rubber adheres more strongly to brass-plated wire than to fibers, thus improving the resistance to separation within the body of the tire as it flexes.

Wire cord tires have already given unusual service in tractor-trailer operations — as much as 103,000 miles on original treads and are still running. No blowouts have been reported. In other instances, wire cord tires with a retread have run 120,000 miles and remained in service.

B. Darrow of our company informs me that several sets of wire logger tires, being tested under actual field conditions in the Pacific Northwest, have run triple the mileage of conventional tires and are still going strong.

Therefore it is expected that wire tires will be used where very severe service is required.

Harry P. Coats
Chief Chemist and Metallurgist
Firestone Steel Products Co.

Predicting Creep Strength

East Pittsburgh, Pa.

To the Readers of Metal Progress:

Referring to the method for predicting creep strength proposed by Kelvin Sproule in the March issue (pages 440-B and 441), it seems desirable to suggest caution in any extrapolation to lower temperatures. Creep tests at elevated temperatures often indicate an approximate inverse proportionality between temperature and logarithm of stress (for a given deformation and time). Such tests usually cover a relatively small temperature range and the validity of the straight-line relation is confined to different temperature ranges for different materials. This is illustrated in the Data Sheet on page 440-B by the departures from straight lines of the curves representing stainless steel Types 304 and 330.

When a straight line is drawn on this Data Sheet with the slope indicated dotted for copper, it is equivalent to a statement that an increase in temperature of 150° F. will divide the stress by 10. Starting from the given value of 3100 psi. at 400° F., this leads to estimates of 310 psi. at 550° F. and 31 psi. at 700° F. which are not unreasonable.

In the other direction, however, the same straight-line relation requires that the stress be multiplied by 10 for each decrease in temperature of 150° F. This would lead to estimates of 31,000 psi. at 250° F. and 310,000 psi. at 100° F. which are obviously incorrect. Tests at lower temperatures indicate that the curves of temperature versus logarithm of stress for copper alloys bend to the left in a manner similar to that shown for low-carbon 18-8 (Type 304), with the result that creep stresses at but slightly elevated temperatures are much lower than the proposed method would indicate.

It is convenient to use a chart of this kind for interpolation between known values and for estimates of the effect of somewhat higher temperatures such as the author has made. Any assumption that the same procedure may be used to estimate stresses at temperatures *lower* than those for which creep data are available is questionable, and unreasonably high estimates of stress may be expected to follow such use.

P. G. McVetty
Manager, Strength of Materials Section
Research Laboratories, Westinghouse Electric Corp.

British Laboratory for Physical Metallurgy

London, England

To the Readers of Metal Progress:

New laboratories are in the course of construction at Battersea, London, England, designed primarily for research in physical metallurgy. Work there will consist of fundamental experiments to back up the investigations of the various divisions of the British Iron & Steel Research Assoc., whose director is Sir Charles Goodeve, which, in full cooperation with British industry, investigates the major problems encountered in ferrous metallurgy. The premises cover an area of 13,000 sq.ft. and will house the entire physics department whose head is M. W. Thring. The program of work is split into five sections — general physics, instruments, heat and thermodynamics, aerodynamics, and mathematics and theoretical physics. Research work is already well under way, although builders are still carrying out constructional work and installing services.

The section on general physics is to initiate experiments on the viscosity of liquid steel in order to throw light on the mode of flow of steel streams from furnaces and ladles. Supersonic techniques are to be applied to the study of fatigue of steel specimens before cracks can be detected, backed up by measurement of the variations in their magnetic properties and resistance to high-frequency currents. Models employing low melting point materials, such as paraffin wax or lead, will be used to investigate heat transfer, shrinkage and cooling zones — this in connection with studies of proposed methods for continuous casting.

The instrument section is to develop new measuring techniques, and maintain a liaison service between the instrument manufacturers and the iron and steel industry. They are now experimenting on a means for measuring the tension in wire during drawing processes, based on the accurate measurement of the frequency of oscillation of a short length of the wire while in motion. It is also hoped to develop a useful torque meter for rolling mills, using electrical strain gages with slip rings for connecting them to electrical measuring and recording devices.

Many attempts have been made to control bessemer blows by spectrographic observation of the flame, but accuracy has generally been lacking. It is possible that this scheme will be feasible when using a photoelectric cell with an electron multiplier and suitably colored filters to give an indication when various lines — for example, the manganese green line — appear in the converter flame. Preliminary work is also being carried out in the instrument section on an automatic optical pyrometer, in which a cell is used purely to match the radiation from a standardized lamp with that from the hot body under observation. In this way, errors due to changes in the characteristics of the cell are avoided. Measurement of radiations from low temperature sources by the lead sulphide infrared radiation detector is also a problem for early investigation.

In the heat and thermodynamics section of the new laboratory, total radiation pyrometers of two commercial designs are ready for test. With them the observer sights on the flame of an openhearth furnace and makes a continuous record of the flame radiating power. A black-body furnace with a 3-in. aperture, capable of reaching temperatures in excess of 3000° F. (1600° C.) is under construction for the accurate laboratory comparison of different methods of measuring openhearth roof temperatures. Other research tools include a contact surface pyrometer for steel billets, and a sensible heat meter for measuring the total heat content of gases at any point in a furnace system, both of which will enable a detailed heat balance to be set up.

A series of aerodynamical experiments has been carried out to find that shape of gas port in an openhearth furnace which will result in the highest gas velocity for a given pressure drop and quantity of gas.

The mathematics and theoretical physics section hopes to establish the theoretical background for the use of oxygen in the blast furnace and in steel refining, the heat transfer in continuous casting, surface pyrometry, and the use of model furnaces to study full-scale processes.

TOM BISHOP
Associate Editor
Iron & Coal Trades Review

German Radiographic Practices

CALIFON, N. J.

To the Readers of METAL PROGRESS:

Three reports on industrial X-rays as used in Germany during the war have been declassified, and are now obtainable from the technical service bureau of the U. S. Department of Commerce in Washington. They are listed as follows:

No. 482. Investigation of the X-Ray Industry in Germany.
No. 535. The Industrial X-Ray Field in Germany.
No. 554. German Practice in Industrial and Military Radiography.

These reports, for the most part, contain information from the manufacturers of X-ray equipment rather than by workers in the field. To be sure, there is nothing new about any of the things mentioned; practically all this information was available to us before the war, and most of the literature cited had been included in the 1943 Edition of "Industrial Radiology" and our supplementary "Bibliography, 1945". Practically all illustrations from Report No. 554 have been in our possession since long before the war.

The importance of the "oxtail tube" has been recognized and emphasized by the writer ever since it became commercially available in Europe in 1936. Despite repeated efforts before and during the war, we have not been able to purchase one of these tubes. Even today, none are available in this country except those the Army and Navy brought back from Germany, where most industrial installations were equipped with this type of tube.

The author of Report No. 554 must have been thoroughly impressed by the German specifications DIN 54110, which he included in translation. The technique described therein is based on admittedly poor penetrameters and thus obtains misleading results. When Ancel St. John suggested the present A.S.M.E. penetrameters (which have been adopted in one form or another by all American agencies), we made extensive tests at our laboratory with all possible gage materials, including the one in use in Germany. We discarded all except the type recommended by the A.S.M.E., and even this should only be used for test purposes rather than for routine inspection. It is much more important that the man who is in charge of such responsible work be thoroughly familiar with radiographic technique and well qualified for the job. This is far better than to give the operator a long list of instructions (as in DIN 54110) which he cannot follow anyway unless he is experienced in this work — and then he does not need such directions. No American, nor anyone who takes pride in his profession, would stand for such regimentation as expressed in DIN 54110.

While the American investigators found some fluoroscopic units in use in Germany, they were employed because of an extreme film shortage, and the results were known to be unreliable for most purposes. If X-ray inspection is actually required, a photographic record should be obtained to get the best results, and to retain a permanent record.

As far as the results are concerned, the same is true for gamma-ray inspection. Radium should only be employed when X-rays are impracticable. We have taken this attitude from our very first 1930 experience with radium, and see now that this has been the final German conclusion. Before the war, the Germans used thorium and mesothorium rather than radium; the results are the same. From the report it seems that they did not use radioactive materials to any great extent.

Another fact evident from these reports is that specially constructed industrial X-ray units have been in general use, rather than converted medical equipment. In nearly all installations the tube formed a separate unit, as adjustable and adaptable as possible — no single-tank, self-rectified machines as is customary in this country, nor voltages above 250 kv. While it may be advantageous to have million-volt machines and even betatrons, they are not important enough in ordinary routine metallurgical work to warrant the great expense.

Little can be learned from these reports as to accessories. While two types of film are mentioned, we do not know what they are. Considerable use of intensifying screens has been made, even for gamma-ray exposures.

HERBERT R. ISENBURGER
President
St. John X-Ray Laboratory

Dimensional stability in quenched tools and dies requires an intelligent program of tempering even though cooling to subzero temperatures has preceded the reheating. It also appears that high speed tools, double tempered, have considerably better cutting performance in lathes if they are held at 500° F. during the cooling from the tempering heat.

TEMPERING OF TOOLSTEELS (Part II)

By MORRIS COHEN

Professor of Physical Metallurgy, Mass. Institute of Technology, Cambridge

IN THE FIRST part of the "Sauveur Memorial Lecture" before the Boston Chapter ⊜ (the portion printed in *Metal Progress* last month, pages 781 to 788) some transformation curves for 18-4-1 high speed steel were presented which demonstrated that austenite started to transform to martensite in this typical toolsteel at 420° F. but that only 80% of it would so change by the time the cooling had proceeded to normal room temperature, and the remaining 20% was relatively stable as long as the temperature was neither raised by tempering nor lowered by refrigeration. We then proceeded to examine the changes both in the freshly quenched martensite and the retained austenite during the heating, holding and cooling stages of a simple tempering operation, correlating such information as was available from microscopic examination, X-ray diffraction analysis, magnetic and volume changes. Finally it was shown that the four recognizable stages of tempering occur isothermally, and therefore *time* is a factor in all the reactions.

Proceeding now we will consider in more detail the problem of dimensional stability that results from the tempering already discussed. Figure and tabular numbers will be continuous with those of the first portion.

Dimensional Stability — Its Relation to the Tempering Process

It is against the structural background developed in the first portion of the lecture that we now view the problem of dimensional instability of hardened steel. In Fig. 10 changes in length are plotted that occur at room temperature in a 1.5% chromium, 1% carbon die steel after oil hardening from 1550° F. and aging at room temperature, and similar changes occurring after tempering at the indicated temperatures for 1 hr. The lengths were measured with great precision to a few millionths of an inch per inch. Evidently the causes responsible are quite complex, some tempering leading to spontaneous contraction at room temperature, some to growth, and some to

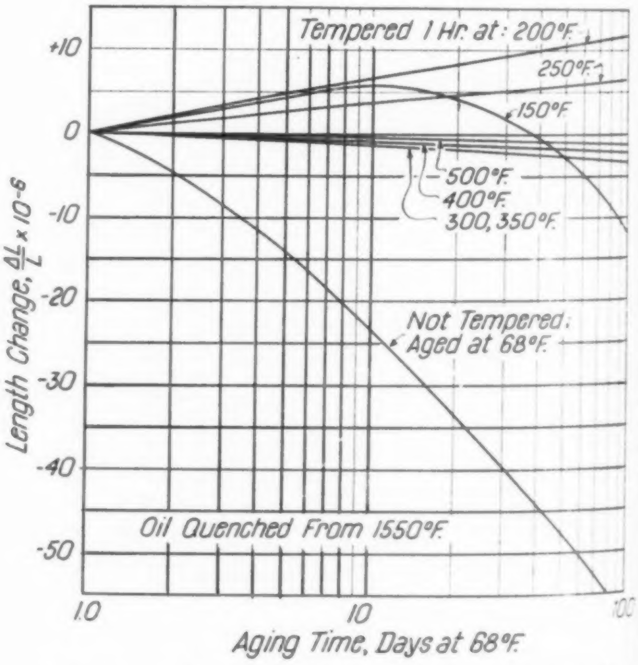

Fig. 10 — Effect of Tempering at the Indicated Temperatures for 1 Hr. on Subsequent Dimensional Stability at Room Temperature of a 1% Carbon, 1.5% Chromium Toolsteel. (Averbach)

both in succession. Is it any wonder, then, that the dimensional instability of steel is such a confusing problem to toolmakers?

However, this complicated situation can be resolved in terms of the martensite and austenite transformations. For example, if this steel is subzero hardened to convert most of the retained austenite into martensite and then put through the same tests, all the stability curves fall into the systematic pattern shown in Fig. 11. The expansional effects are suppressed, and we find the true contractional trend of the martensite alone. The higher the tempering temperature, the more the martensite contracts *during* tempering, and the less it contracts on subsequent aging at room temperature.

By subtracting the curves in Fig. 11 from their mates in Fig. 10 and making certain corrections for the changes occurring within the first day, we can determine the expansion effect due to the transformation of the austenite retained at room temperature. Figure 12 indicates that the expansion is greatest in the as-hardened steel, and becomes less the higher the tempering temperature (zero at 500° F. in this 1% carbon, 1.5% chromium toolsteel). This behavior is not because *all* the retained austenite is transformed by the tempering, but is due to the fact that tempering *stabilizes* the austenite and makes it resistant to gradual transformation at room temperature. Tempering at 250° F certainly does not convert an appreciable amount of austenite into bainite or martensite, yet the curve for 250° F. in Fig. 12 is surprisingly flat, compared to the untempered curve. The phenomenon is undoubtedly one of stabilization.

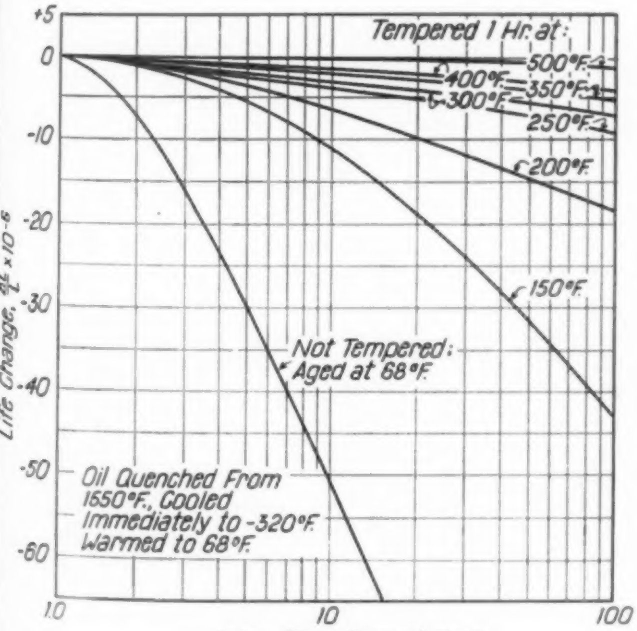

Fig. 11 — Effect of Tempering for 1 Hr. on Subsequent Dimensional Stability at Room Temperature of the Same Chromium Toolsteel After Subzero Hardening at —320° F. Prior to Tempering. (Averbach)

Up to the present time, it is not known whether the gradual transformation of austenite in freshly quenched steel as it ages at room temperature is a very early part of the "second stage" of tempering or an entirely different process. In any event, the extent of this change is very small, being of the order of 1% austenite.

Sluggish Austenite — The Plot Thickens

When toolsteels are highly alloyed, as in high speed steel, the retained austenite is very sluggish and does not undergo the customary at-temperature transformation in the range of 400 to 600° F. However, there is another way to transform the retained austenite — namely, by heating it in the range of 900 to 1100° F.

Fortunately for us, the coexisting martensite, being highly alloyed, does not soften excessively at these temperatures. In such a treatment, the austenite does not transform to any appreciable extent while staying at the tempering temperature, but rather on cooling therefrom.

Figure 13 illustrates how the course of this cooling transformation is related to the tempering treatment. If hardened 18-4-1 is tempered at

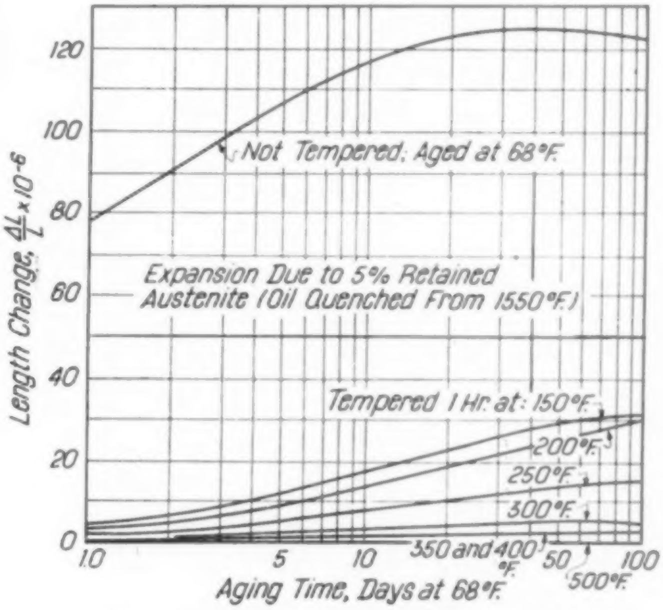

Fig. 12 — Effect of 1-Hr. Tempering on the Contribution of Retained Austenite in the Same Toolsteel to Dimensional Instability at Room Temperature. (Averbach)

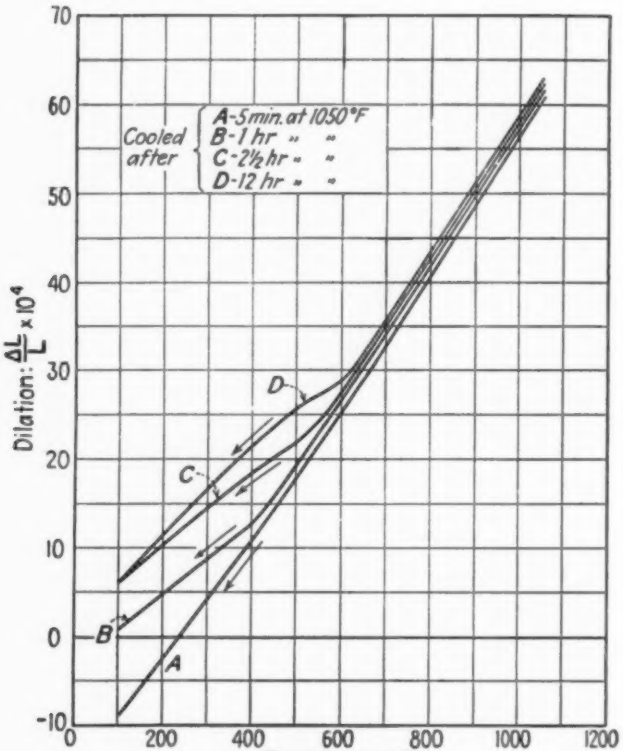

Fig. 13 — Dilation Curves Showing the Effect of Tempering Time at 1050° F. on the Subsequent Transformation of the Retained Austenite in 18-4-1 Toolsteel During Cooling. (Koh)

1050° F. for only 5 min. (curve *A*), the cooling contraction curve to room temperature is normal, the contraction being approximately proportional to the temperature drop. This means that no transformation occurs on cooling.

But if the tempering time is increased to 1 hr. (curve *B*), some transformation occurs on cooling, as shown by the expansion starting at 400° F. superimposed on the normal contraction curve. After 2½ hr. at 1050° F. (curve *C*), there is still more transformation, and in fact this treatment, like the 12-hr. temper (curve *D*), achieves virtually complete transformation of the retained austenite when room temperature is reached. The tempering really "conditions" the austenite for transformation during cooling.

The cooling transformation has all the characteristics of an austenite → martensite transformation, and the product *is* martensite, even though air cooling is involved. We shall call it "secondary martensite" to distinguish it from the "primary martensite" formed in the hardening quench. As we have seen from Fig. 1, the retained austenite in the as-hardened steel has its martensite range below room temperature (cold treatment would convert a substantial part of it). However, the tempering at 1050° F. is believed to change the composition of the austenite retained in this highly alloyed toolsteel by causing alloy carbides to precipitate out of it. This decreases both the carbon and alloy content of the austenite, and thereby raises its martensite range above room temperature. Hence, martensite forms when the tempered steel cools to room temperature after the tempering operation. If enough carbide is precipitated, the martensite range is raised sufficiently so that all the austenite is so transformed. The precipitation process and the secondary martensite formed cause the well-known secondary hardening of high speed steel.

The hardness changes on tempering high speed steel can be plotted against the Hollomon-Jaffe parameter with the constant = 19.0. As indicated in Table II, the maximum secondary hardening occurs at a parameter equal to 28,250, and the calculated times for various temperatures are compared with the observed values. The time-temperature conditions for the *complete* conversion of the retained austenite are represented by a parameter of 29,200, and such calculations are also compared with the observed values in Table II. The agreement is quite good.

Table II — Time-Temperature Combinations for Maximum Secondary Hardening and for Complete Conversion of Austenite in 18-4-1 High Speed Steel

Austenitizing temperature = 2350° F. $P = T(\log t + 19.0)$
P = 28,250 for maximum secondary hardening
= 29,200 for complete conversion of retained austenite

TEMPERING TEMPERATURE	T (°F. + 459)	TEMPERING TIME IN HOURS			
		MAXIMUM SECONDARY HARDENING		COMPLETE CONVERSION OF RETAINED AUSTENITE	
		CALCULATED	OBSERVED	CALCULATED	OBSERVED
950° F.	1409	11.0	10.0	60.0	70.0
1000	1459	2.5	2.5	10.0	10.0
1050	1509	0.57 (34 min.)	0.50 (30 min.)	2.4	2.5
1100	1559	0.13 (8 min.)	0.10 (6 min.)	0.56 (34 min.)	0.50 (30 min.)
1125	1584	0.066 (4 min.)	0.05 (3 min.)	0.26 (16 min.)	0.25 (15 min.)

Multiple Tempering — Double or Triple?

It is now an old story that double tempering is beneficial to high speed steel, and of course the reason is that the transformation of austenite during the cooling from the first tempering produces a batch of new and untempered martensite, and also sets up new stresses because of the volume changes occurring in the hard steel at relatively low temperatures. If we can adjust the first tempering to convert all the austenite, then the second temper merely becomes a stress relieving and toughening operation, there being no more martensite formed on cooling from the second draw. Less than one point in hardness on the Rockwell C-scale is lost by double tempering, and even this loss may be eliminated by using 950° F. for the second temper.

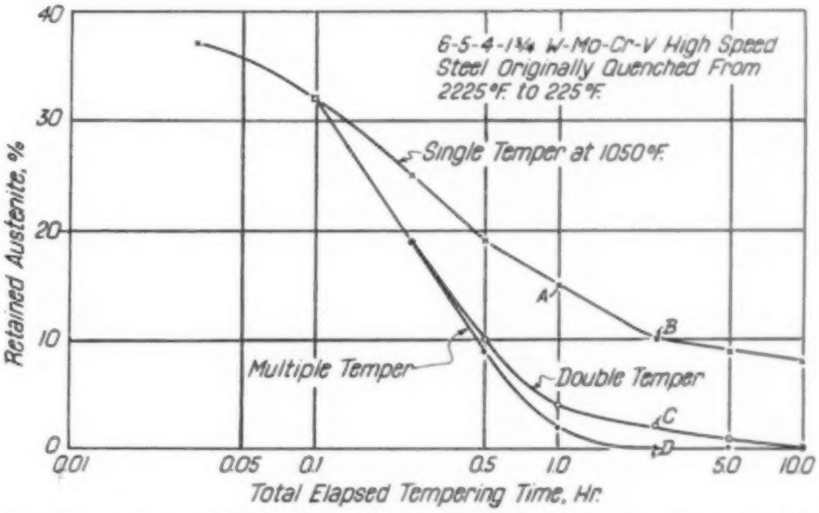

Fig. 14 — Effect of Single, Double and Repeated Tempering at 1050° F. After Arrested Hardening of 6-5-4-1¾ High Speed Steel. (Gordon)

Table III — Effect of Various Tempering Combinations on Transverse Strength of High Speed Steel

6-5-4-1¾ W-Mo-Cr-V steel quenched from 2225° F.

Designation	Temperature of Quenching Bath	Tempering Treatments at 1050° F.		Modulus of Rupture	Comparative Strength
		Number	Time		
1	80° F.	1	2½ hr.	434,000 psi.	100%
2	80	2	2½ + 1	490,000	113
3	225	1	2½	309,000	71
4	225	2	1 + 1½	377,000	87
5	225	3	1 + 1½ + 1	445,000	103

There are instances where *triple* tempering of high speed steel is justified. This happens when the hardening quench is not carried all the way to room temperature before going into the draw, as is sometimes done to avoid quenching cracks. The austenite → martensite transformation is then stopped prematurely, and an unduly large amount of austenite remains and goes into the tempering treatment. Under these circumstances it becomes exceedingly difficult to convert all of the retained austenite in a single tempering cycle. This is shown in Fig. 14 which plots results of experiments on a tungsten-molybdenum high speed steel whose quench was interrupted at 225° and followed by a tempering at 1050° F. without prior cooling to room temperature. Tempering once for 1 hr. leaves 15% austenite (Point *A*), and 2½ hr. still leaves 10% (Point *B*). Even if the tempering is prolonged for 10 hr., 8% austenite remains. The reason for this ineffectual tempering is that there is about 55% austenite in the freshly quenched steel at 225° F., and abnormally long tempering times are needed to "condition" such amounts of austenite; whereas if the steel were cooled all the way to room temperature, there would only be 20%.

However, even 55% austenite responds to double tempering. For example, after tempering 1 hr. if specimen *A* is heated again for 1½ hr. at 1050° F. to make a total time of 2½ hr., 2% austenite is left (Point *C*), and if repeated tempering is used, again with an accumulated time of 2½ hr., no austenite remains (Point *D*).

Thus, when large quantities of austenite are involved, double or multiple tempering is more effective than single tempering in conditioning the austenite for transformation.

What is the practical importance of these considerations? This is shown in Table III in terms of transverse bend strength for the same tungsten-molybdenum high speed steel. Suppose we say that normal hardening to room temperature followed by tempering for 2½ hr. at 1050° F. produces a bend strength rating of 100% (434,000 psi.). Then the interrupted cooling at 225° followed by the same temper drops the strength

down to 71%. This, as we have demonstrated, is because a single 2½-hr. draw is entirely inadequate after arrested hardening. However, if the tempering is done in two cycles of 1 + 1½ hr., thus converting practically all the austenite, the strength rises to 87%, but a third temper of 1 hr. to toughen the last increment of martensite, and to relieve the stresses formed during its transformation, increases the strength to 103%.

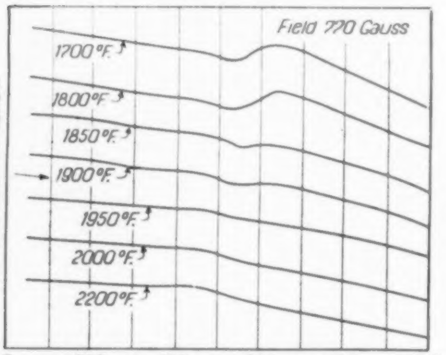

Fig. 15 — Magnetic Changes in 1% C, 5% Cr Steel During Slow Reheating After Oil Quenching From Temperatures Shown. (Zmeskal)

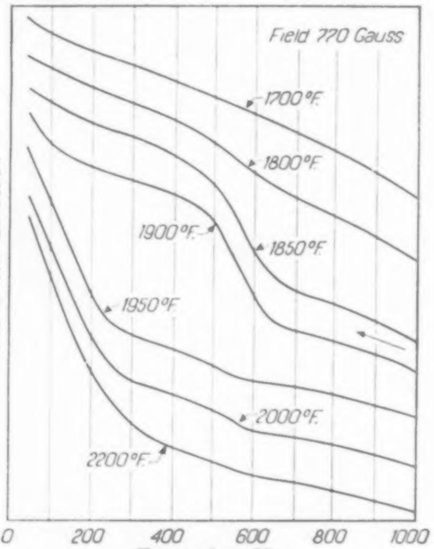

Fig. 16 — Magnetic Changes in Samples of Fig. 15 After Holding 2 Hr. at 1000° F. and During Slow Cooling. (Read From Right to Left)

Hence, we see that arrested hardening will yield inferior strength unless the tempering is properly executed, but, with appropriate tempering, very respectable strength values can be obtained, despite the arrested hardening. On the other hand, if the hardening can be carried all the way to room temperature, one 2½-hr. temper will "take care" of the retained austenite, and a second temper raises the strength to 113%.

As a rule, then, we want to use a tempering treatment after the austenite is *entirely* converted, because the transformation of the final portion produces internal stresses and some untempered martensite. If the austenite conversion requires one draw, then double tempering is indicated. If two draws are necessary to convert all the austenite, then triple tempering is indicated.

Austenite of Intermediate Stability — The Missing Link

In passing from the plain carbon and low-alloy toolsteels to the high speed steels, we have seen how transformation of the retained austenite changes radically from an isothermal process in the range of 400 to 600° F. to a martensite-type of reaction on cooling from 1000° F. ±100°. In the highly alloyed steel, the austenite becomes so sluggish in its tendency toward reaction that it will resist transformation in the lower temperature range and hence can be exposed to a carbide-precipitation process ("conditioning") at higher temperatures, which makes this austenite more susceptible to transformation on cooling.

Now the questions arise, "What is the difference between the low-alloy and the high-alloy austenites?" and "Is it a difference in degree or in kind?" These questions can be answered by studying high-carbon, high-chromium toolsteel, in which the retained austenite can be made to assume a wide range of stabilities by adjusting the hardening temperature. (The correlations that I am about to draw apply equally well to 1% carbon, 5% chromium steels and the 1.5% carbon, 12% chromium grades, but we shall use the former for discussion.)

In Fig. 15 and 16 are some magnetic tempering curves for samples of 1% carbon, 5% chromium steel, oil quenched from various temperatures between 1700 and 2200° F. After hardening, the samples were heated slowly to a tempering temperature of 1000° F., held there for 2 hr. and then cooled slowly (5° F. per min.) to room temperature. The changes in magnetization during heating are given in Fig. 15 and during cooling in Fig. 16 (plotted from right to left). During the stay at 1000° F. no magnetic changes were observed. The curves are arbitrarily spaced at convenient intervals to avoid overlapping; therefore the starting positions are not indicative of the amounts of retained austenite present, which actually varied from about 15% after hardening at 1700° F. to over 80% after hardening at 2200° F. But we are not interested just now in the amount of retained austenite, only in its stability.

The principal aspect of these curves is the superimposed "bumps" which denote the transformation of the retained austenite. In the sample quenched from 1700° F., the austenite

transforms on heating in the range of 500 to 600° F. This converts all the austenite because no evidence of transformation is found in the corresponding cooling curve (top line of Fig. 16). Obviously the retained austenite after a quench from a low hardening heat is not very stable, and transforms on moderate reheating just as it does in the low-alloy steels. In fact, this austenite will transform isothermally below 500° F.

However, as the hardening temperature is raised, and more carbides are dissolved in the austenite, it becomes more sluggish, and we note that the transformation during heating becomes less and less — it is not displaced to higher temperature, but is suppressed. Correspondingly, the transformation on cooling after tempering 2 hr. at 1000° F. becomes progressively more important. The cooling transformation results from the "conditioning", or the carbide-precipitation process that occurs during the time the steel stays at 1000° F.

It turns out that the product of austenite transformation during cooling of the samples previously hardened from 1850 and 1900° F. is not martensite, because the upward bend in the magnetization-temperature curve can be avoided by rapid cooling. The product is actually bainite,* and so is the product formed in the same temperature range during *heating* of the specimens quenched from 1700, 1800, 1850 and 1900° F. (Fig. 15). Because of the increased stability of the austenite in the specimens quenched from 1950 and 2000° F., there is no bainite produced on heating and only a small amount on cooling, while in the sample quenched from 2200° F. (bottom curves in Fig. 15 and 16) there is no appreciable transformation in the bainite range whether on heating or cooling. We do find a transformation in the 1900 to 2200° F. samples when the temperature after the draw falls below 300° F. This cannot be suppressed by quenching from the tempering heat, and the product indicated by the sharp upward bend in the three lower curves of Fig. 16 is martensite. The lower four curves in Fig. 16 illustrate how the extent of the martensite transformation increases as the bainite transformation is gradually suppressed by the increasing stability of the austenite formed at the higher quenching heats. It is evident that the 2200° F. curve represents a situation comparable to that prevailing in the tempering of high speed steel.

As a matter of fact, high speed steel — which normally forms martensite on cooling from the tempering — can be made to undergo a bainite transformation if the cooling is stopped in the proper temperature range. This is shown in Fig. 17, which indicates that the optimum temperature for such a reaction is 500° F. in an 18-4-1 steel hardened at 2350 and tempered for 2½ hr. at 1050° F. At this temperature, the austenite transformation into bainite is almost complete in 24 hr., transformation is 75% complete in 4 hr., and only 50% complete in 1 hr.

G. K. Baer and Peter Payson† have recently performed cutting tests with high speed steel double tempered in the usual way, and with similar tools that were held at 460° F. on cooling from the tempering to form secondary bainite instead of secondary martensite. The final hardness was C-64 to 65 in either case. Table IV is from their data. The tools were 1 x ½-in. lathe bits cutting S.A.E. 2340 bars in both continuous cutting and in interrupted cutting. In the latter tests, the bar had a slot milled in it so that the tip of the tool

Series of Oil Baths, Electrically Heated and Automatically Controlled for Tempering Small Tools. (Pratt & Whitney Co.)

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*The bainite produced by tempering is called "secondary bainite" to distinguish it from the "primary bainite" formed isothermally during austempering.

†"The Bainitic Hardening of High Speed Steel"; paper presented at National Metal Congress, November 19, 1946.

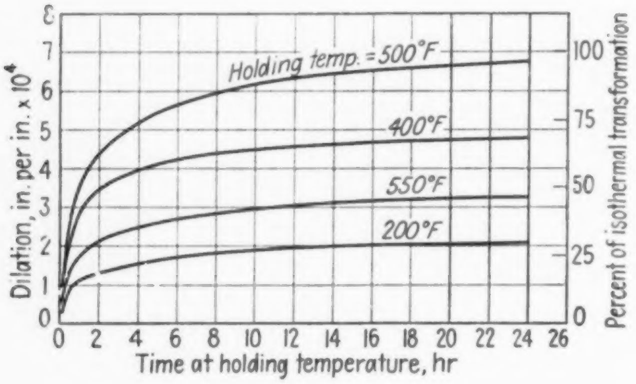

Fig. 17 — Bainite Formation From Retained Austenite in 18-4-1 High Speed Steel as a Function of Time of Holding During Interrupted Cooling From the Tempering Temperature. Austenitized at 2350° F.; tempered at 1050° F. for 2½ hr. (Pope)

received an impact on each revolution. It will be noted that there is a general improvement in cutting performance in the tools containing secondary bainite, over the tools hardened by double tempering. The extent of improvement varies from steel to steel, and from continuous to interrupted cutting; however, the beneficial trend is unmistakable.

This in an interesting example of academic research leading to a new type of heat treatment which may have practical importance.

Table IV — Effect of Secondary Bainite on Lathe Tool Performance
(Baer and Payson)

TYPE OF STEEL	AUSTENITIZING TEMPERATURE	TEMPERING TREATMENT	RELATIVE PERFORMANCE	
			CONTINUOUS CUTTING	INTERRUPTED CUTTING
18-4-1 W-Cr-V	2350° F.	Double temper*	100 (standard)	100 (standard)
		Secondary bainite†	100	117
18-4-1 + 5% Co	2350	Double temper*	162	5
		Secondary bainite†	179	156
5½-4-4-1½ W-Mo-Cr-V	2350	Double temper*	100	182
		Secondary bainite†	150	138
5½-4-4-1½ + 5% Co	2350	Double temper*	201	33
		Secondary bainite†	242	59

*2 hr. at 1050° F., air cooled to room temperature, 2 hr. at 1050° F., air cooled to room temperature.
†4 hr. at 1050° F., cooled to 460° F., held 7 hr. at 460° F., air cooled to room temperature (there being no subsequent tempering).

The Tempering Process — Resumé

And now we must stop and take a broad glimpse of the picture of tempering that we have developed here. We have seen that hardening is a remarkable process, but it leaves the steel in a brittle, highly stressed and dimensionally unstable condition. We have also found that tempering is something more than just a mere softening operation. Rather, it is a moderating process used to obtain optimum combinations of properties under controlled temperature and time of heating.

As applied to toolsteels, commercial tempering involves the transformation of the tetragonal martensite and the partial relief of internal stresses. What happens to the retained austenite depends upon the type of steel; in plain carbon and low-alloy steels, the austenite will transform isothermally in the range of 400 to 600° F., but since these steels are usually tempered below 450° F., some austenite remains in the steel. However, this remaining austenite is stabilized by the tempering. In the highly alloyed steels, the austenite resists transformation in the 400 to 600° F. range, and can therefore be conditioned at 900 to 1100° F. so it will transform to martensite on cooling from the draw. In such steels, double tempering is advantageous, for it relieves the stresses and toughens the martensite formed during cooling from the first draw. If the austenite is very sluggish, *two* tempers may be needed for converting the austenite to a hard product, and then a third temper is in order.

These two behaviors of retained austenite are the two extreme examples of a general pattern. The tempering of the high-carbon, high-chromium steels provides the connecting link, and gives us a unified picture of the entire gamut of toolsteel compositions.

Thus, there is beginning to emerge a science of tempering, which should take its rightful place beside the science of hardening. ◆

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STAINLESS STEEL SIMPLIFIES PRODUCTION . . . The high ductility of "18-8" makes severe drawing operations easy. Here, one man places a stainless steel blank in the press, while the other stacks a stamping.

COMPONENT PARTS OF BARRELS ON WAY TO WELDERS . . . Tops, shown at left, bottoms, at center, and middle sections, on upper right, move on huge conveyor belts to welding department, to be joined together into a finished Firestone product.

● **Yes, you can draw the mighty valuable conclusions that . . .** "18-8" stainless steel not only responds readily to forming operations, but also permits ready fabrication by welding.

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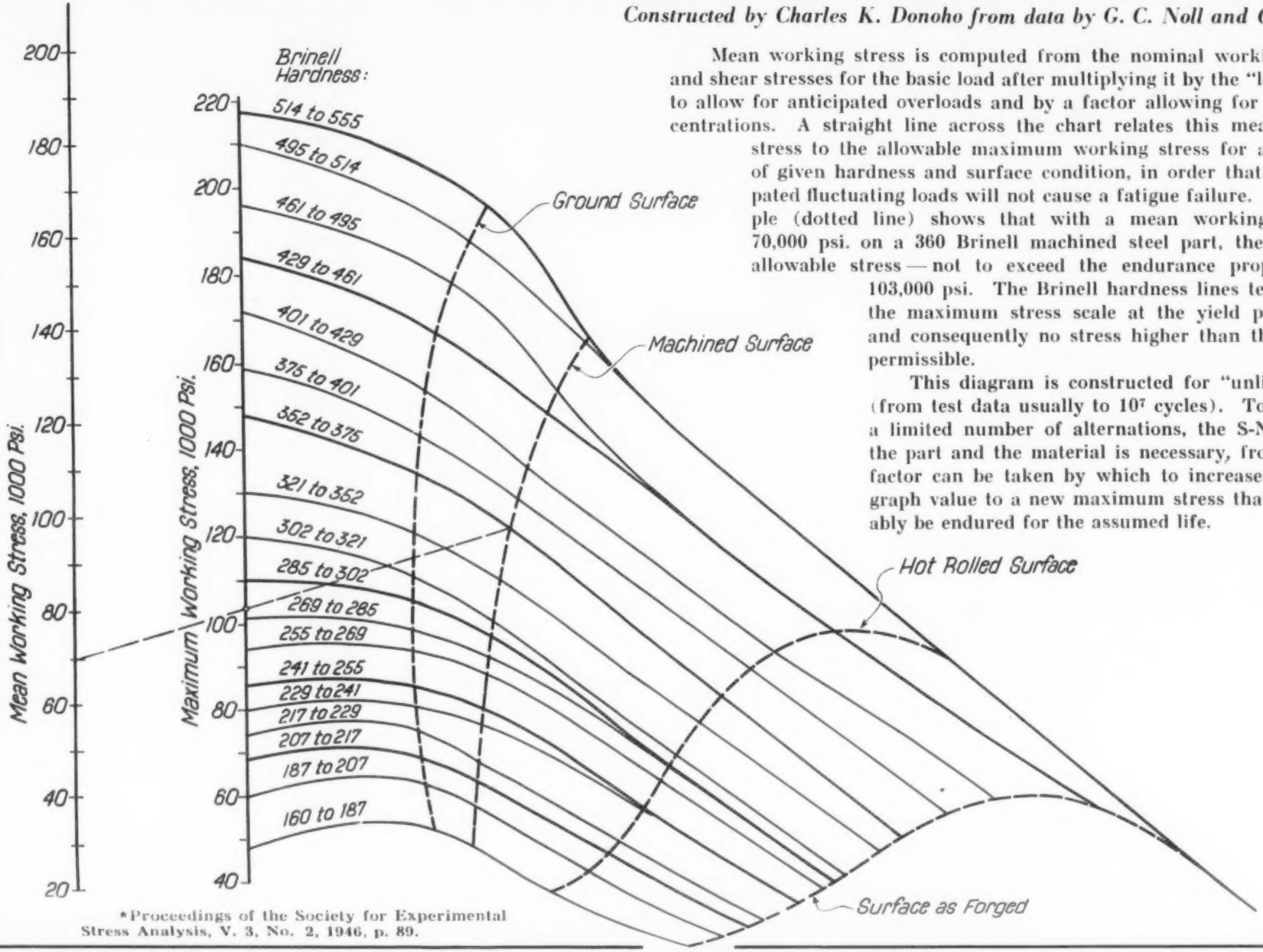
Nomograph for Allowable Working Stresses in Steel Parts

*Constructed by Charles K. Donoho from data by G. C. Noll and C. Lipson**

Mean working stress is computed from the nominal working normal and shear stresses for the basic load after multiplying it by the "load factor" to allow for anticipated overloads and by a factor allowing for stress concentrations. A straight line across the chart relates this mean working stress to the allowable maximum working stress for a steel part of given hardness and surface condition, in order that the anticipated fluctuating loads will not cause a fatigue failure. The example (dotted line) shows that with a mean working stress of 70,000 psi. on a 360 Brinell machined steel part, the maximum allowable stress — not to exceed the endurance properties — is 103,000 psi. The Brinell hardness lines terminate on the maximum stress scale at the yield point stress, and consequently no stress higher than this value is permissible.

This diagram is constructed for "unlimited" life (from test data usually to 10^7 cycles). To design for a limited number of alternations, the S-N curve for the part and the material is necessary, from which a factor can be taken by which to increase the nomograph value to a new maximum stress that will probably be endured for the assumed life.



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*Proceedings of the Society for Experimental Stress Analysis, V. 3, No. 2, 1946, p. 89.

A department for notes on important metallurgical trifles — short cuts and labor-savers in plant and laboratory. An ● book of your own choosing for submitting an acceptable item.

BITS AND PIECES

Model Sleeve and Ring Bearings

WE HAVE found a great advantage in making lucite (transparent plastic) models of motor bearings and studying the flow of oil under various speeds and loads. It enables our designing engineers to *see* what is happening, and improve the bearings for larger factor of safety, smaller bulk, or increased load.

Blocks of lucite are machined to close tolerances, just like metal, to form full scale models of bearings with all retaining rings, oil grooves and other details. The plastic bearing is then erected and supported exactly as the metal counterpart would be in the journals. A regular steel shaft is provided and the rotating element is operated by a hand crank for slow speeds, and motor-driven for high speeds.

Oil, colored with red pigment, is fed into the bearing model and the lubrication effectiveness quickly is apparent. We can see at once whether the seals work properly, whether the oil passages provide a proper flow of lubricant, and whether the relief points are located correctly. All this formerly had to be determined very largely by trial and error. If the oil passages are not in the right position, some areas will be "starved" for oil and the bearing cannot carry a full load. This, in turn, reduces the amount of work which the motor can handle. (JOHN BOYD, research engineer, Westinghouse Electric Corp.)

Computations of Tensile Results

TWO CALCULATIONS frequently required in tensile testing of round specimens need tedious arithmetic when solved in a straightforward manner. These are the determination of tensile strength in psi. and the reduction of area in %. Both may be solved rapidly on any slide rule by manipulations not given in most text books. Neither is original, but both deserve wider use.

In the instructions below, the rule designations of A, B, C, D are those on standard slide rules. Also let d be the original diameter of the round specimen and d_n the diameter of the necked portion after fracture.

I. Knowing d and the breaking strength in pounds, to find tensile strength in psi.: Over d on D scale set 1.128 on C scale. Under "pounds break" on A scale (either half), read psi. on the B scale.

Example: 0.109-in. wire; breaking strength 793 lb. Over 0.109 on D set 1.128; under 793 on A, read 85,000 psi. on B.

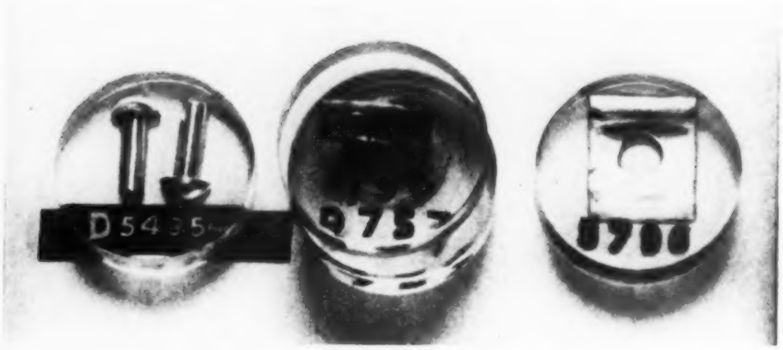
II. Knowing the original diameter d and the reduced neck diameter d_n, after fracture, to find RA (reduction of area in %): Set d on C scale over d_n on D scale. Over right-end-unity of B scale, read (100 − RA) on scale A.

Example: 0.506 in., original diameter d; 0.253 in., necked diameter d_n. Set 0.506 on C scale over 0.253 on D; over unity at right end of B read 25% on A. RA = 100 − 25 = 75%.

Both problems are solved much easier than the descriptions indicate, require no tables of areas or squares, and the results are sufficiently accurate for all routine purposes. (J. DUNLAP MCNAIR, metallurgist, Indiana Steel & Wire Co.)

Identifying Metallographic Specimens

RECENT notes about identification of transparent mounts warrant mention of a method used for several years. All that is required are small, inexpensive paper letters and numbers made by label manufacturers. During the mounting process, the letters are placed in order just below the surface of the plastic, above the back of the



specimen. (If translucent plastic is used, care should be taken to place the characters close to the surface.)

Since letters and figures are obtainable in various sizes, types, and colors, several combinations are possible. For example, a particular color may be employed to denote a certain experiment or class of specimens. By placing the characters beside the specimen, they can be read when the latter is inverted and can be spotted readily when several specimens are stacked. By using letters and numbers together, samples can be represented with a minimum of characters in each specimen. (M. H. Kalina, supervisor of ferrous metallurgy, Armour Research Foundation)

Rapid Polish for Silver Plate

A METHOD for electropolishing silver plate, recently adopted in Westinghouse research laboratories for silvered contactors, switchgear items, radio apparatus and experimental devices needing bright silver coatings, was discovered quite by accident, yet has entirely replaced hand buffing.

In the course of a study of microwave tubes it was necessary to clean thoroughly some phosphor bronze diaphragms about the size of a dime. The job proved particularly difficult, and so a cyanide electrocleaning solution was tried, one of the diaphragms being suspended by a wire that had previously been used in a silver bath. This wire had a dull white appearance, but when the phosphor bronze diaphragm was lifted out of the cleaning solution the wire had taken on a brilliant luster.

After the essential items had been separated from the accidental phases of this experiment, a simple process could be evolved:

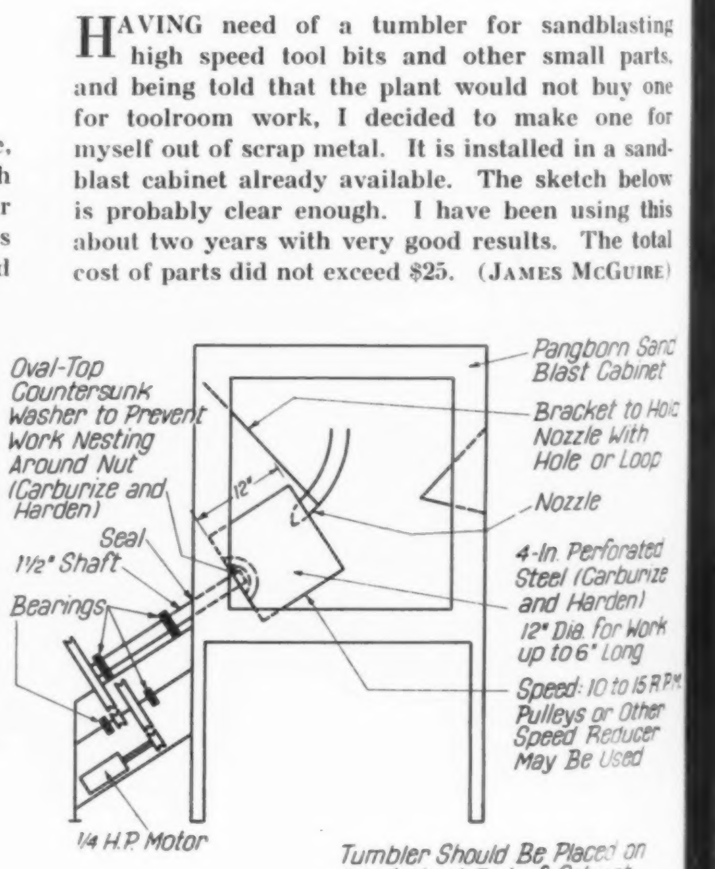
The plated part is immersed in an ordinary silver plating bath of silver cyanide solution. Instead of sending negative current through the bath as in plating, however, positive current is applied in about four times the amperage used to plate the metal, but not continuously. The positive energy is applied for a few seconds, discontinued, then sent through again, and this intermittent action repeated for several cycles. When the article has reached its peak of luster, it is taken out of the bath, rinsed, and dried. The entire operation takes little more than a minute.

Current can easily be interrupted by a motor-driven switch. Ideal industrial practice would be to place the metal pieces in the plating bath, send through negative current to silver-plate them, then intermittent positive charges to attain the bright finish.

Besides eliminating the whole buffing process, this new procedure would have the advantage of retaining, right in the original solution, the small quantity of silver removed while polishing. (Dennis R. Turner, physicist, electronics dept., Westinghouse Research Laboratories)

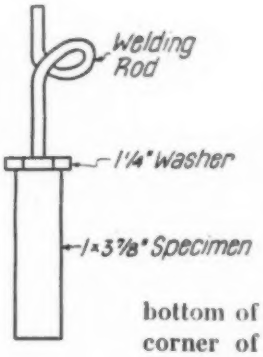
Tumbler for Small Tool Bits

HAVING need of a tumbler for sandblasting high speed tool bits and other small parts, and being told that the plant would not buy one for toolroom work, I decided to make one for myself out of scrap metal. It is installed in a sandblast cabinet already available. The sketch below is probably clear enough. I have been using this about two years with very good results. The total cost of parts did not exceed $25. (James McGuire)


Oval-Top Countersunk Washer to Prevent Work Nesting Around Nut (Carburize and Harden)
Seal
1½" Shaft
Bearings
¼ H.P. Motor
12"
Pangborn Sand Blast Cabinet
Bracket to Hold Nozzle With Hole or Loop
Nozzle
4-In. Perforated Steel (Carburize and Harden) 12" Dia. for Work up to 6" Long
Speed: 10 to 15 R.P.M. Pulleys or Other Speed Reducer May Be Used
Tumbler Should Be Placed on Least Used End of Cabinet

Simplified Jominy Test Piece

WE RUN many Jominy tests for hardenability in our heat treat laboratory. We found that time may be saved by turning a 1x3⅞-in. specimen from the steel stock, without the customary ⅛-in. shoulder. This shoulder is replaced by tack welding a large washer on one end of the bar. The welding rod is left fastened to the same end, serving as a hanger for suspending the bar in a neutral salt bath at 1550° F. for 1 hr.; it also allows the bar to be carried to the quenching fixture. After quenching the bar, the rod and washer can be knocked off very easily before grinding the 0.015-in. flats for the hardness measurements. By this means we are able to perform Jominy tests more quickly and conveniently than by using a one-piece specimen. (HARRY F. ROSS, Delco-Remy Div., General Motors Corp.)

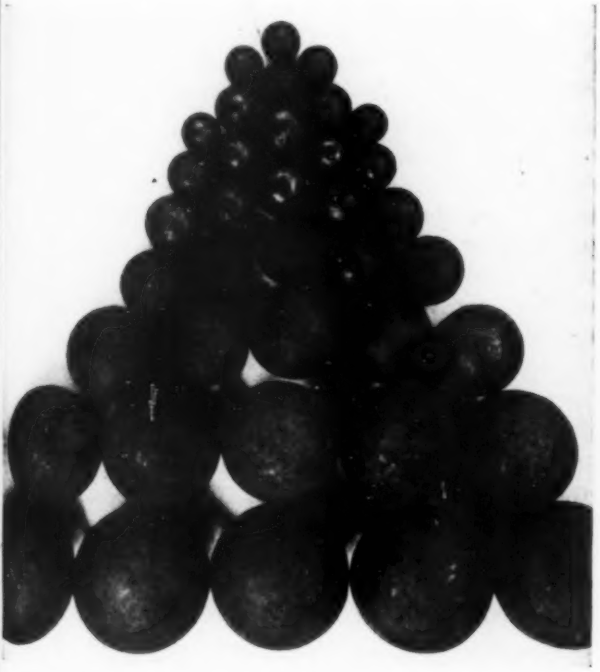


Photomacrographic Procedure

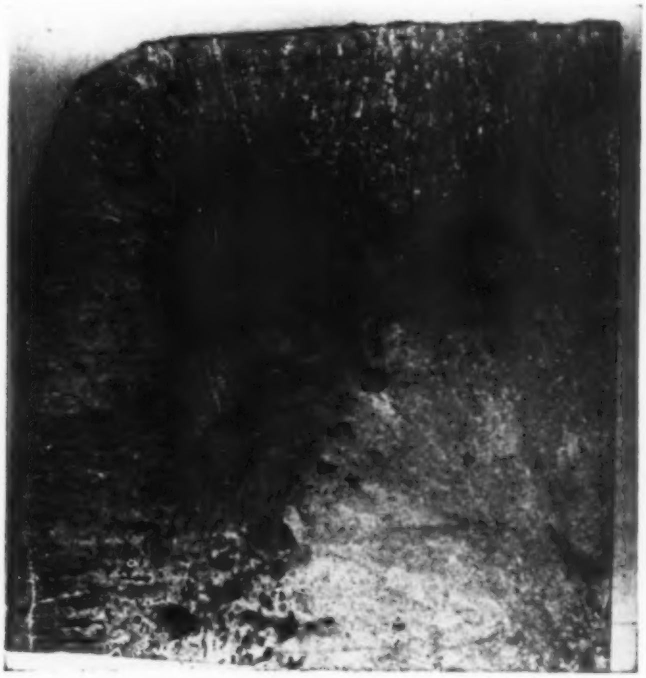
THE METHOD for photomacrography used in Sheffield Steel Corp. laboratory apparently deserves wider use, since the results were adjudged to be prize winners in the photographic exhibit at the last ⊕ Metal Congress (Atlantic City, November 1946). For etched sections we use 15-watt daylight fluorescent lamps for illumination, and the Bausch & Lomb II-B Tessar lens at f-45, either for a small reduction in size or all magnifications up to 4 diameters. For higher magnification we use either the Bausch & Lomb 72-mm. or 32-mm. Micro-Tessar lenses. At the bottom of the column is shown a cross section of a corner of a rejected ingot using this method of illumination. The original magnification was ⅔ natural size; the print has been reduced half linear in making the half-tone. Note especially that fairly deep cavities are illuminated sufficiently so that the bottom contour is plain.

We use Wratten & Wainwright metallographic plate for photographs of samples that have been etched or broken to show structure. On the other hand Eastman No. 33 plate gives good detail for material in the natural state, such as the forged balls.

The second photograph submitted is of 4, 3½, 2, 1 and ⅞-in. forged grinding balls. In the original plate the 4-in. ball was reduced to appear as a 1½-in. circle. Pictures of this type require the best the lens has, to get all in focus and give the depth of field required for a clear photograph. We find the Bausch & Lomb II-B Tessar serves nicely for this work. (C. PATRICK KENYON, chief metallographer, Sheffield Steel Corp.)



Forged Balls for Grinding Mills. Original print 0.4 natural size; print reduced half size in engraving



Etched Section of Blowy Ingot. Original print ⅔ natural size; print reduced half size in engraving

IRON AND STEEL MANUFACTURE

Conference Reported by RALPH W. FARLEY
Special Mill Metallurgist, Chicago District, Republic Steel Corp.

THE LATEST and largest conference of the Openhearth, Coke Oven, Blast Furnace, and Raw Materials Committees of the American Institute of Mining and Metallurgical Engineers was held in Cincinnati late in April. The three-day program started with a visit to the American Rolling Mill Co.'s coke and iron plant at Hamilton and steel plant at Middletown, Ohio. Conferees inspected the sinter plant, processing 1500 tons per day in continuous operation, and two blast furnaces of 900 and 750-ton capacity operating on a burden of about 55% sinter. At the steel plant, hot metal from the mixer ladles is desiliconized with roll scale before charging in the openhearth, thus affording a decided advantage in chemical control of the refining. The openhearth shop has eight furnaces of 160 to 190-ton capacity. One furnace was being rebuilt with all basic brick, except for the roof. These furnaces have a forced draft fan at the outlet of each chamber; fuel economy is very good. Vacuum cleaning of checkers is used.

The bulk of the product is low-carbon steel and ingot iron, rimmed or fully-killed, nonaging type. Track and pit times are under close control. Slabs up to 72 in. wide are rolled, using a set of conical turning rolls when necessary to broadside into the mill. Slabs are skin-scarfed hot on top and bottom, but the edges are not conditioned. No hand scarfing is done. Slabs pass through the reheating furnace to the strip mill, where sheet and strip to 80 in. wide can be rolled on five roughing and six finishing stands.

The McKune Award this year was conferred on a paper discussing the direct oxidation of the openhearth bath, presented by Edward B. Hughes of Wheeling Steel Corp. In that practice, oxygen at 100-lb. pressure is blown directly into the bath. Since most of the steel produced at the author's plant is under 0.07% carbon, this realizes important savings in time, fuel and ore; likewise fewer cold heats are tapped. The properties of the refined steel are not affected; Mr. Hughes studied carbon-oxygen relations, and found little if any difference in oxygen content of the bath. (This may not be universal, for some investigators are reporting lower oxygen in the bath in their oxygen-blown heats.)

Scrap preparation came into the discussion of raw materials. Trends include larger charging boxes, use of bundling equipment, modern hauling equipment, and incentive systems to encourage the workmen to place the maximum load in boxes.

Hot metal quality assumes increased importance in view of today's scarcity, poor quality, and high prices of scrap. Replies to a questionnaire indicate that 70% of the operators have iron containing between 0.75 and 1.25% silicon; 82% have iron between 1.25 and 2.25% manganese; 90% have between 0.1 and 0.5% phosphorus. Sulphur content of hot metal is of prime importance; when it is high, some can be eliminated in the flush if the manganese is over 2%. 70% use hot metal mixers; and 32% of the operators base their flux additions upon the silicon content of the iron. (Generally flux should also be increased for higher metal charges.) Many operators are considering the installation of bessemer converters because of the growing scarcity and low quality of scrap.

Pig iron substitutes were discussed by both basic and acid openhearth men. Generally no difficulties are encountered at about 50% substitution; attempts at full substitution may bring trouble with furnace bottoms and banks, long melt-down times, and sulphur delays. Too much coal causes foaming. Coal, coke and graphite replace the carbon of pig iron; ferromanganese, spiegel and manganese ore replace the manganese. No adverse effects on quality were reported.

Soft melts may be recarburized by injections of fuel oil; one operator uses a pressure of 175 lb. through a ¼-in. pipe, putting in 100 gal. in 13 min. In state of development is the injection of graphite with air.

In basic foundry practice, deoxidation with aluminum is reported to give good physical properties, provided sufficient is used to leave 0.02 or 0.03% excess aluminum, whereas just enough to deoxidize adversely affects the physicals.*

Hydrogen and its elimination is worrying both basic and acid men. In the basic furnace a good vigorous boil is necessary to wash out this gas under the best conditions; at times it is possible to *pick up* hydrogen even in a good boil! Hydrogen can also be absorbed from an improperly dried ladle. The acid men heard a discussion of gas washing in the ladle; either nitrogen or argon effectively removes hydrogen when blown through the metal to the extent of 4 to 7 cu.ft. per ton. The action must be a mechanical flush rather than a chemical combination. Nitrogen is the less expensive, but argon may be used where nitrogen must also be kept to low limits in the finished steel.

Sulphur has been reduced in acid steel at tap from 0.028 to 0.020% with about 0.3 lb. of sodium per ton. This sodium must be placed under the stream or otherwise submerged to eliminate the explosion hazard.

Fluidity — Investigations have revealed that steel killed in the ladle has greater fluidity than furnace-killed. Fluidity is increased also by allowing the heat to open up slightly after the block.

Oxygen gas was of great interest this year, both in the openhearth as a steelmaking reagent, and for blast enrichment in the blast furnace. Oxygen may be used in the openhearth in three ways — *(a)* to raise flame temperatures with oxy-fuel, *(b)* as a lance to melt down scrap and *(c)* for carbon removal by direct oxidation. Through its use the production of a given furnace may be increased 50%; this figure may be safely expected, perhaps it may even be better. Probably the greatest savings in furnace time are realized when working in the very low carbon ranges. No concrete answer to the question of furnace maintenance was reported; this will take continued experience. The dense reddish smoke produced by direct oxidation will be a nuisance to be controlled; investigations to date fail to reveal any dangerous fumes in this smoke. At any rate, it appears that it can be controlled by washing the furnace smoke in water towers.

Blast enrichment occupied one session of blast furnace men. The Linde-Frankl low pressure process for production of oxygen was developed commercially in Germany before World War II. This country lagged behind until the necessities of war forced us to develop portable units for use by the armed services. Now under construction are four 1000-ton plants to operate at maximum pressure of 80 lb., producing oxygen of 95% purity. The plant cost will run to about $2920 per ton capacity, the operating cost about $2 per ton; very little maintenance is expected. A blast furnace plant for blast enrichment is also being built by one of the large steel companies. An interesting point concerning purity of the resulting gas was the statement that it would be possible to take off about 95% of the output as 95% oxygen and the other 5% as 99+%, suitable for scarfing, cutting and other operations.

Blast enrichment will increase temperatures; it will also raise the partial pressure of CO, thus having the same effect in increasing efficiency as higher top pressure. A quantitative analysis of these and other factors was presented. Among the very challenging questions placed before the meeting were:

Can CO and O_2 be used in the blast? (It could be produced by recycling the exit gas with the oxygen.)

Oxygen is used to produce both hydrogen and carbon monoxide; could these gases be produced in this way and used in direct reduction, or for special atmospheres?

What use can iron and steel men find for the large amount of impure nitrogen which is a byproduct of oxygen production?

In a session on the metallurgy of the **blast furnace process**, a series of challenging questions were thrown out for discussion and further investigation by B. M. Larsen in his paper entitled "Some Questions on Interrelated Processes Going on in the Blast Furnace". (See *Metals Technology*, Feb. 1947, TP 2132.) Recognizing the difficulty of making direct observations and of translating laboratory experience to conditions in the smelting process, Mr. Larsen nevertheless proposes that there are questions which may be further investigated with hope of definitive answers. Fifteen such questions are proposed as a basis for investigation in the laboratory and on plant scale. It is not within the scope of this report to list the questions nor to attempt to abstract the discussion of them. It may be stated that they relate to such subjects as variation of burden, mixing of charge, variation in the processes of reduction, direct and indirect reduction, solution loss of coke and its effects upon heat consumption and temperature distribution in the zones of the furnace, limitations on increasing the temperature or oxygen content of the blast, coke quality, elimination of sulphur, and the critical temperature theory of the process. Operators and investigators alike will accept the challenge of these 15 questions, and much new knowledge of the process should be gained from their study.

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*See abstract of paper "Acid Electric Steel for Castings", by Sam F. Carter and C. K. Donoho, page 992 of this issue.

Pyrometry — The use of platinum versus platinum-rhodium thermocouples for measuring the bath temperature was described to the acid furnace men while the gathering of basic melters heard a paper on the radiation type of pyrometer in use by National Tube Co. Temperatures recorded by couple pyrometers will run 35 to 50° below spoon temperatures read with the optical pyrometer. (Bear in mind that the temperature drop in handling the spoon sample may be of the order of 25 to 50°.) Working with bath pyrometers, skulls and hot heats are under better control, with resulting contributions to steel quality, and the life of furnace, ladle and molds.

Spectrographic methods in use at three mills for determining the lime-silica ratio of basic slags were described in detail. A sample of powdered slag is packed in one of the two electrodes, and the required measurement is by comparison of the densities of suitable lines of calcium and silicon. Agreement with conventional analysis was essentially the same in all three reports, generally well within 10%. The advantage of the method lies in its speed, which enables the chemist to report the ratio to the melter while he is shaping the heat. Best performance is where the spectrographic laboratory is adjacent to the melting floor. Practical results claimed for the method include better control of phosphorus reversions and improved sulphur elimination.†

A new direct-reading spectroscope was described before the section considering acid practice. The instrument is distinguished from the spectrograph by the direct measurement of the intensity of the desired lines by photo-electric cells; thus it does not require the measurement of line intensity on photographic plates. Its advantage lies in its extreme speed; eight elements may be determined in 40 sec.; accuracy and reproducibility are about the same as with the more conventional spectrographic methods. Both arc and spark may be used, the selection being made on the basis of their relative accuracies on the desired range of the elements to be analyzed for.

Sulphur in steel, its sources and elimination, were subjects of serious attention. Purchased scrap, mainly turnings and bundles, is the largest reported source. Pig is apparently under much better control than scrap. Some operators report that they have not observed sulphur pickup from the flame, but two out of six report trouble when sulphur in the fuel is above their specification. The consensus on several factors follows:

> There is no relationship between melt carbon and bath sulphur.
>
> Bath action, high lime, and MnO contents are essential for fast removal.
>
> The best course of action is to take early tests and apply corrective measures in shaping up the heat.
>
> Ferromanganese or spiegel need be used only in emergencies.

Some have noted that sulphur drops faster when oxygen is used in the bath than when it is worked normally; this is usually attributed either to increased agitation or higher temperature.

The effect of sulphur upon quality is generally bad. Some report a correlation between poor surface quality and high melt-in sulphur, regardless of how low it may have been reduced on the ladle tests; others do not find this relationship, but only that usually found between ladle sulphur and surface quality.

Charging Machine in Action at Electric Furnace Shop, Canton, Ohio, Plant, Republic Steel Corp.

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†See "Slag Control by Routine Spectrographic Analysis", by J. T. Rozsa. *Metal Progress*, April issue, p. 593.

Oxygen content of liquid steel entered the discussion with a paper by C. E. Sims on "The Mechanism of the Carbon-Oxygen Reaction in Steelmaking". A very realistic diagram was presented showing how oxygen enters the bath from the furnace atmosphere by way of the slag, or from iron ore directly, and how CO is formed by precipitation at the hearth and then on bubbles as they arise. The diagram was drawn for the electric furnace, but of course is equally valid for the openhearth. Some of the important contributions to the physical chemistry of this reaction were interpreted in terms of this mechanism. A finite degree of solubility of CO in liquid steel is accepted by the writer on the basis of considerable indirect evidence such as the following: Small increases in CO solubility with carbon content would account for observed increases in $\%C \times \%O$ with carbon content. Increases in pressure of CO, over one atmosphere and up to about seven, due to ferrostatic pressure and inherent resistance to bubble formation, would account for oxygen contents above those required by the equilibrium constant $m = \%C \times \%O = 0.00222$ at one atmosphere CO, termed $\Delta[o]$ by Brower and Larsen.* Since the rate of carbon drop has been found to be a logarithmic function of the carbon content, and the pressure of CO a square root function of carbon, the author points out that the carbon drop is controlled by the CO pressure. Using $m = 0.00222$ and the observed relationship between %C and CO pressure for the steady state, the following expression is proposed:

$$\%C \times \%O = 0.00222 \times 8.7\ (\sqrt{\%C} - 0.09)$$

which checks with the observed $\Delta[o]$ down to about 0.1% C.

Evidence was mentioned that the oxygen content of steel blown with oxygen is lower than that of steel worked with ore. May not this be due to the flush of oxygen lessening the resistance to formation of CO bubbles, thus reducing $\Delta[o]$? During the lime boil, with its flush of CO_2, $\Delta[o]$ is found to be lower (and during working of ore it is higher) than in the steady state.

In the discussion of deoxidation, a question was placed before the meeting which brought out lively discussion: "Why block the heat?" With modern analytical methods long holds are not necessary. Blocking does not have much effect in lowering the oxygen content, nor upon cleanliness, and an undesirable absorption of hydrogen may occur. In reply to this question, the consensus seemed to be in favor of the block. It was pointed out that there is no direct relation between $\Delta[o]$ and inclusions. The meeting was also reminded that oxidation is controlled by carbon and temperature. Furnace deoxidation does not form inclusions in the furnace; emulsification of slag and such factors are involved. In the melting of 8637 steel one speaker found that blocking with ⅓ lb. aluminum and 13 lb. silicomanganese per ton was desirable for highest quality.

Ingot Molds — Discussion of ingot molds was taken up where it left off last year. Evidence was presented that greater mold life is obtained in heavy molds over thin walls, in big-end-down over big-end-up, in small molds over large, in solid bottom types and with graphite inserts, and by elimination of stickers. Mold foundry practice, but not the composition of mold metal, has been found to influence mold life. Wider mold spacing on cars is a potent factor in increasing life.

Thin-walled molds are reported to yield thinner skinned ingots than do heavy walls. The initial chilling is a little faster, but since the heat capacity of thin walls is lower, the chilling rate falls off sooner.

Solidification rates of ingots have been studied. The curve expressing the depth frozen as a function of the square root of time is in the form of two parabolas, the first representing columnar crystallization, the second equiaxed. Steel with varying superheat freezes in the same total time, but the time to produce columnar crystallization is longer for the hotter steel, and the columnar structure is deeper.

Surface quality of slabs from large molds is improved by larger nozzles and increased rate of rise. On 0.15 to 0.25% C grades, killed or semi-killed, however, smaller nozzles are found to produce better surface.

A method in use to cut the hold time of killed, hot topped ingots by water cooling was described. The hold time was originally two hours. Now the hot tops are filled with water three times, starting 45 min. after pour, then the ingots are pulled and stripped immediately. Care in handling is exercised because the interior is still molten. Both track and pit time is shortened; pour-to-roll time is cut to 3 or 3½ hr. High ingot quality is required, and it does not suffer by this treatment. Pipe is found below the collar, but it is clean and separated by a bridge from the main shrink cavity; thus it gives no trouble. Yield from these ingots is increased by 4%. Check analysis is uniform and mold life is improved.

In conclusion, it is to be hoped that the above summary will transmit a few specific ideas, gleaned from a packed meeting, a verbatim account of which will occupy a volume. ●

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*"Oxygen in Liquid Openhearth Steel — Oxygen Content During the Refining Period", *Metals Technology*, Sept. 1946, TP 2035.

IDENTIFICATION OF DELTA CONSTITUENT IN ALUMINUM BRONZES

By DAVID J. MACK and M. A. SHURMAN
Asst. Prof. of Metallurgy / Dept. of Chemical Engineering
College of Engineering, University of Wisconsin, Madison

IN DETERMINING the eutectoid temperature in aluminum bronzes by metallographic methods, it is desirable to have an etching reagent which will attack or darken only the delta phase without affecting other metallographic constituents. Such a reagent will readily identify the first traces of delta in the alpha-plus-delta eutectoid as it forms from the beta solid solution. It is also useful for identifying pro-eutectoid delta in hypereutectoid alloys.

All of the common etching reagents used or recommended for aluminum bronzes, and there are five basic types plus several modifications listed by C. H. Davis in his article on etching copper alloys in ⊕ *Metals Handbook*, page 1471 (1939 Edition), have either one, or both, of two disadvantages. This remark also applies to the excellent all-purpose electrolytic reagent consisting of 1% chromic acid in water described by W. C. Coons and D. J. Blickwede in ⊕ *Transactions*, V. 35, 1945, p. 284. These disadvantages are:

1. They attack not only the delta in the lamellar eutectoid but the acicular eutectoid as well. The acicular eutectoid is formed, of course, from beta during the quench to room temperature from the suspected eutectoid temperature under investigation. Thus, the lamellar and acicular eutectoids cannot be positively distinguished from each other, even at high magnification, particularly when only traces of the lamellar form are present.

2. They attack the iron-aluminum compound present in most commercial aluminum bronzes in exactly the same way they attack the delta in the eutectoid, thus making separation of these two microconstituents difficult. Positive identification of small amounts of delta in the presence of the iron-aluminum compound is further complicated by the fact that both have the same bluish color in the unetched condition.

A reagent has been accidentally discovered which overcomes both of the above disadvantages. It is the familiar ammonium hydroxide and hydrogen peroxide solution, but used only after it is aged two to nine days in a loosely stoppered bottle. The proportions of the constituents are not critical, but the writers find that 25 ml. of NH_4OH, 25 ml. of H_2O and 20 ml. of 3% pharmaceutical H_2O_2 works very well. The aging period seems to be quite critical for usable results. If the reagent is less than two days old it acts as does the usual hydroxide-peroxide mixture on all microconstituents; if more than nine days old, its action is like that of straight NH_4OH of the same concentration. Five to seven days aging gives a slow, readily controllable etch, first darkening only the delta and then faintly attacking the acicular eutectoid.

Realizing that such an aging period is a disadvantage, numerous methods were tried to accelerate the aging or eliminate its necessity, such as decreasing the amount of H_2O_2 to only a trace, warming the freshly prepared solution, boiling or aerating the fresh solution, or boiling and aerating both, substituting other oxidizing agents for the H_2O_2, and so on. None of these gave any results at all. What happens during the aging period is a complete mystery to the writers, but the fact

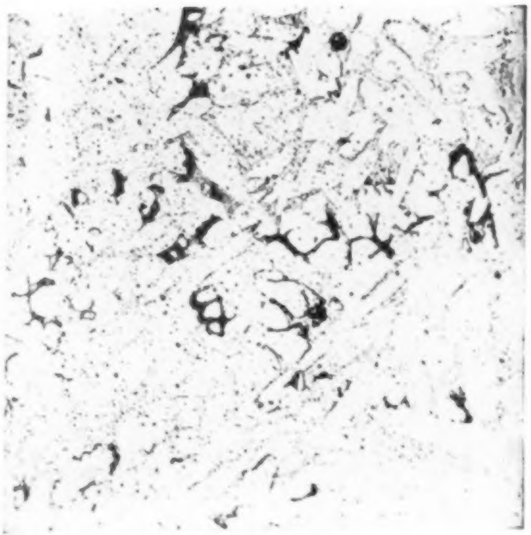


Fig. 1 — Persulphate Etch, 100 ×. Areas of lamellar eutectoid etch much darker than the acicular eutectoid, but small areas of the lamellar are lost in the groundmass

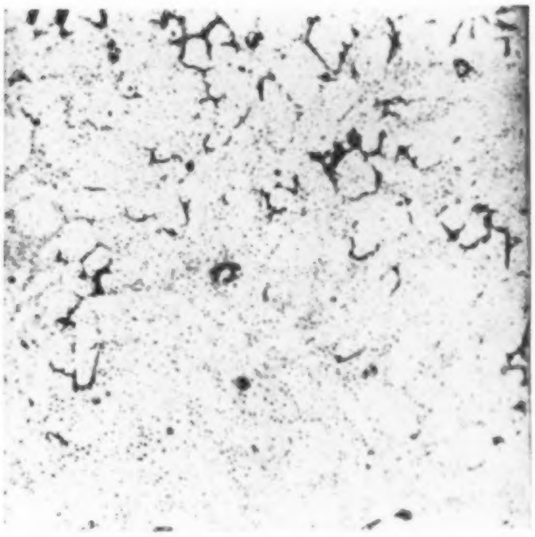


Fig. 2 — Sample Etched With Stale Hydroxide-Peroxide Reagent; Magnified 100 ×. Appearance is almost identical with Fig. 1 except that the acicular eutectoid is less darkened and less sharp

remains, the reagent works as stated.

Comparison of the action of the stale hydroxide-peroxide reagent with the 10% ammonium persulphate reagent, at 100 and at 500 diameters magnification, is given in Fig. 1 to 4. The same sample of alloy was used although the fields are not identical. The material contained 87.3% copper, 9.14% aluminum and 3.4% iron. Ammonium persulphate was chosen as the comparison etchant because it gives results most nearly comparable, but inferior to, the hydroxide-peroxide solution, aged five days.

The iron-aluminum particles are visible in Fig. 2 at 100 × because of polish relief and not because of attack by the stale hydroxide-peroxide reagent. Note that none appear in Fig. 4, taken at 500 ×. In Fig. 3, also at 500 ×, the delta in the eutectoid and the compound are both darkened by the ammonium persulphate, and the boundaries of the acicular eutectoid are sharply outlined. Figure 4 (stale hydroxide-peroxide etch) shows the sharpness of the etch on the delta in the lamellar eutectoid and the much fainter etch on the acicular eutectoid. The iron-aluminum compound is unattacked. At 500 × hair-like filaments of delta on the boundary between the acicular eutectoid and the alpha cannot be confused with the boundary itself, as in Fig. 3.

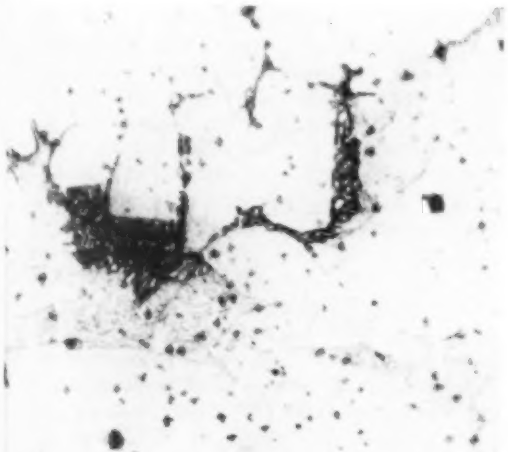


Fig. 3 — Same as Fig. 1 But Magnified 500 ×

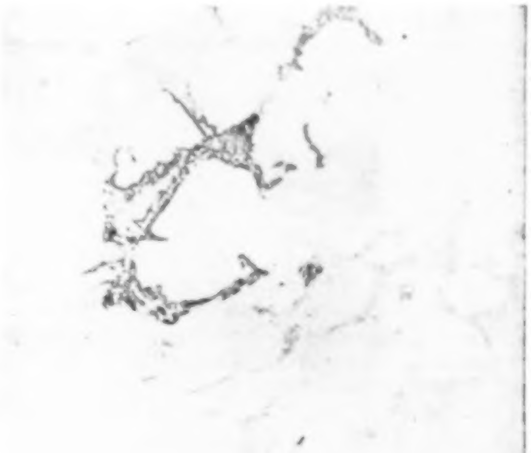


Fig. 4 — Same as Fig. 2 But Magnified 500 ×

United States Atomic Energy Commission

By Myron Weiss

On April 9, 1947, five civilians, including one professional scientist, became potentially the most powerful group in this nation. President Truman had in October appointed them to make up the Atomic Energy Commission and as such to carry out the mandate of our "Atomic Energy Act of 1946" which in its first paragraph says: "It is hereby declared to be the policy of the people of the United States that, subject at all times to the paramount objective of assuring the common defense and security, the development and utilization of atomic energy shall, so far as practicable, be directed toward improving the public welfare, increasing the standard of living, strengthening free competition in private enterprise, and promoting world peace."

To do that the new commissioners took authority on Jan. 1 over 55,000 persons and $1,500,000,000 of installations at Oak Ridge, Tenn., Pasco, Wash., and Los Alamos, N. M., the Clinton Laboratory at Oak Ridge, the Argonne National Laboratory at Chicago, the Brookhaven National Laboratory on Long Island, N. Y., the to-be-built Knolls Atomic Power Laboratory at Schenectady, and lesser facilities and activities already existing in two dozen other sites.

All this was, as the *New York Times* editorialized, just a small beginning. Since, by law, the Commission is to own all fissionable materials existing in the United States (it now being "unlawful for any person to own any fissionable material"), all processing plants, all processes and technical information, and "all facilities and equipment devoted primarily to atomic energy research and development", its creation establishes an area of socialized endeavor whose expansion will doubtless have great but unpredictable influence on our entire national economy based on private initiative and capitalistic rewards.

It would be thought that such an important group would command salaries at least equal to those of executives in the movie industry, but commissioners get $15,000 a year, except the chairman who gets $17,000. The latter, particularly, got a severe man-handling as well, in the Senate prior to his confirmation to office on April 9.

It is desirable to know something about these men as persons.

David Eli Lilienthal, the chairman, is now 47. He graduated from Harvard Law School (a disciple of then Prof. Felix Frankfurter), began practicing law in Chicago and got married. It was a solid start for the young man. His Chicago law partner was Donald Richberg who then was counsel for that city in public utilities matters, and who later became an early Roosevelt braintruster. Tidy-minded Lawyer Lilienthal attracted the attention of Governor Philip LaFollette of Wisconsin who wanted his state's railroad commission overhauled; before Lilienthal finished he had completely revised the Wisconsin statutes pertaining to public utilities. They became models for other states.

President Roosevelt then appointed him, in 1933, one of the original three directors of the Tennessee Valley Authority. Soon he was running that vast organization, beating down privately capitalized public utilities and modernizing the living habits of a large part of that area.

As worker he is intense, introspective, systematic, precise.

As family man he has raised a daughter Nancy Alice, who has graduated from Radcliffe, and a son David Eli, who is still in college. The family was raised at Norris, Tenn., where family life is methodical and intellectual. Father Lilienthal enjoys an occasional picnic.

As public administrator Lilienthal had this significant part of his philosophy to express at a recent conference of the National Municipal League: "Because the central Government through the Congress must and should determine upon a national policy in a particular field, it does not by any means always follow that the administration of that policy must also be on a nationwide basis, must also be centralized. The distinction between authority and its administration is a vital one. The problem is to divorce the two ideas of authority and administration-of-authority."

When President Truman announced that he would make authoritarian Lilienthal (who advocates an International Atomic Energy Authority) chairman of the Atomic Energy Commission, a great controversy started between friends and enemies, which came to a head in the Senate hearings, but confirmation was eventually by a substantial majority. In one of his first public statements thereafter, Chairman Lilienthal said:

"The United States now has a head start. Are we to maintain and increase that pre-eminence? Will we fool along or politic along? What our course shall be will depend upon how important forward strides in atomic development appear to the American people, depend upon how well the whole American people understand the essential facts, understand the human implications. Since Hiroshima, we have actually gone downhill, measured in such vital factors as scientific personnel, depreciation of plants, intensity of effort. To face the facts of lost drive — this is the beginning point of any understanding by realistic men of what America's course should be from here on out."

Robert Fox Bacher (rhymes with "locker"), 41, nuclear physicist, is the only scientist among the five commissioners. Like most of the top physicists and chemists of this country, he has worked at several American universities, picking his knowledge where it was best available. He has studied at the University of Michigan, California Institute of Technology, and Massachusetts Institute of Technology, has taught at Columbia and Cornell, and at the radiation laboratory of M.I.T. did outstanding wartime development work which ended in controlled and practical nuclear fission.

Press Asso., Inc.

Sumner T. Pike — Lewis L. Strauss — President Truman — David E. Lilienthal — Robert F. Bacher — William W. Waymack

During the engineering of the first atomic bombs, Dr. Bacher was chief of the "bomb physics division" of the Los Alamos Laboratory. Then, until his new appointment, he returned to his professorship at Cornell, where he was naturally head of nuclear research.

While he was active with the bomb developments, he made special studies on the inspection and control of atomic energy production. Bernard M. Baruch, in arguing for strict international controls before the United Nations' Committee, relied heavily upon Dr. Bacher's knowledge and his clarity of exposition. He was one of the dozen U. S. scientists who tersely announced less than a year ago: "Without uranium as a raw material there is no foreseeable method of releasing atomic energy. With uranium, thorium can also be used. Denaturing — though valuable in adding to the flexibility of a system of controls — cannot of itself eliminate the dangers of atomic warfare."

Dr. Bacher was among the score of international scientists who advised the United Nations' Atomic Energy Committee: "We do not find any basis in the available scientific facts for supposing the effective control [of atomic energy] is not technologically feasible." As to whether or not it is *politically* feasible, he and his international associates left that to international statesmen.

Sumner T. Pike, 57, is a well informed, quick thinking, easy talking Down-Easter who ran away from his Maine home when a boy and wound up selling equipment to the booming oil industry of Texas. Stone & Webster, the big-scale engineering concern with a genius for the financing of corporations, took on Salesman Pike. Case, Pomeroy & Co. of Wall Street took him away from Stone & Webster. The war pulled him into public administration, as director of the fuel division of the Office of Price Administration. Thence he went to the Securities and Exchange Commission, which he quit last March, telling President Truman: "I am getting stale on the job."

Lewis Lichtenstein Strauss (rhymes with "toss"), 51, born in Charleston, W. Va., educated in Richmond, Va., could not afford the college education in physics that he wanted, but he got a job on the Belgian relief staff of Herbert Hoover, became Mr. Hoover's private secretary, met Banker Mortimer Schiff at the Paris peace conference that followed World War I, got a job in Mr. Schiff's bank (Kuhn, Loeb & Co.), became a Kuhn-Loeb partner himself (in 1929). A few years ago Banker Strauss had cosmic-ray physicist Robert A. Millikan as apartment guest in New York and got him to autograph Millikan and Gales' "A First Course in Physics" which student Strauss had used in his Richmond high school days. That 1906 textbook contained only seven pages on radioactivity. During World War II Banker Strauss — as Rear Admiral Strauss — was the Navy's member on the Interdepartmental Committee on Atomic Energy.

When World War II began for the U. S. he was called to active duty from the Naval Reserve, became staff assistant to the Chief of the Bureau of Ordnance, special assistant to Secretary of the Navy Forrestal (another onetime Wall Street man), Navy member of the Army-Navy Munitions Board. His son, just out of the Navy, is studying physics at Harvard.

As a banker's avocation in communal and philanthropic work, he has helped the Princeton Institute for Advanced Study at the top levels, and the Metropolitan Opera Association. He is a notable anti-antisemitist. As atomic energy commissioner, Banker Strauss has had to quit various directorships in great corporations. He feels, he recently said, "like a man who is amputating his own leg".

William Wesley Waymack, 58, resigned editor and vice-president of the Des Moines *Register and Tribune,* is the nearest of the five to being a trained philosopher, sociologist and humanitarian. He is active in learned societies of diverse fields, has twice won Pulitzer prizes for his editorials, has traveled far and studiously (most recently as an official U. S. observer of elections in Greece). One of the jobs from which his new job compelled him to resign was the board of directors of the Chicago Federal Reserve Bank.

General Manager

Carroll L. Wilson, 36, engineer, of Framingham, Mass., has been appointed to be the general manager, at $15,000 yearly salary, to carry out the orders and directives of this five-man atomic energy commission. He is to get four assistants, at $14,000 yearly, to direct research, production, engineering and military applications.

General Manager Wilson replaces General Leslie R. Groves who has been commander since the Army began its atomic bomb developments. His age and even younger appearance are deceptive. He grew up a "wonder child", a "prodigy" who was graduated from Massachusetts Institute of Technology when only 18. By the good fortune of attracting the attention of M.I.T.'s president, Karl T. Compton, the youth escaped the attrition by which fond relatives and harsh jobs wear down most such brilliant young men. Compton kept him as personal assistant, and he later became special assistant to develop a program of administering patents on inventions by M.I.T. staff members.

This brought Carroll L. Wilson in touch with big industries and made him highly regarded by an influential coterie of perspicacious scientists as an able and realistic administrator. With the approach of the war, he became a member of the National Defense Research Committee, later executive assistant to Dr. Bush, director of the Office of Scientific Research and Development.

Advisers to the Commission

To advise the Atomic Energy Commission "on scientific and technical matters relating to materials, production and research and development", President Truman has also appointed these men:

J. Robert Oppenheimer, 42, whom his fellow-committeemen elected their chairman when they held their first meeting. This able physicist (a prewar professor at the University of California and California Institute of Technology) directed the Manhattan District's laboratory at Los Alamos, N. M., whose staff perfected and exploded the first atomic bomb. He was a member of the Secretary of State's atomic energy committee which prepared the so-called Acheson-Lilienthal report on the international control of atomic energy.★ At present he is director of the Institute for Advanced Study at Princeton, N. J.

James Bryant Conant, 53, president of Harvard University, president of the American Association for the Advancement of Science, successor to Dr. Bush as chairman of the Government's National Defense Research Committee, a leading figure in the formation of the atomic energy project, starting as a member of the "top policy group" created in 1941, serving with President Roosevelt, Vice-President Wallace, Secretary of War Stimson, General Marshall and Vannevar Bush.

Lee Alvin DuBridge, 45, president of Cal. Tech. During the war, while dean of the faculty of arts and sciences of the University of Rochester, he directed the O.S.R.D. radiation laboratory at Massachusetts Institute of Technology.

Enrico Fermi, 45, Nobel prizewinner in physics (1938), onetime professor of theoretical physics at the University of Rome, later professor of physics at Columbia University, now professor of physics at the University of Chicago.

Isidor Isaac Rabi, 48, Nobel prizewinner in physics (1944), professor of physics at Columbia University, appointed January 7 to be chairman of scientific advisers to the policy council of a new Joint Research and Development Board of the Army and Navy.

Harley Rowe, vice-president and chief engineer of the United Fruit Co. at Boston.

Glenn Theodore Seaborg, 34, professor of chemistry at the University of California, discoverer (with associates) of three of the four transuranium elements, plutonium 94, americanum 95 and curium 96, who directed a group studying the chemistry of plutonium, first at Berkeley and later at University of Chicago's metallurgical laboratory during the perfection of nuclear fission.

Cyril Stanley Smith ⊕, 43, England-born director of the Institute of Metals of the University of Chicago, during the war head of the chemistry and metallurgy division at Los Alamos, and longtime research metallurgist for the American Brass Co. at Waterbury, Conn.

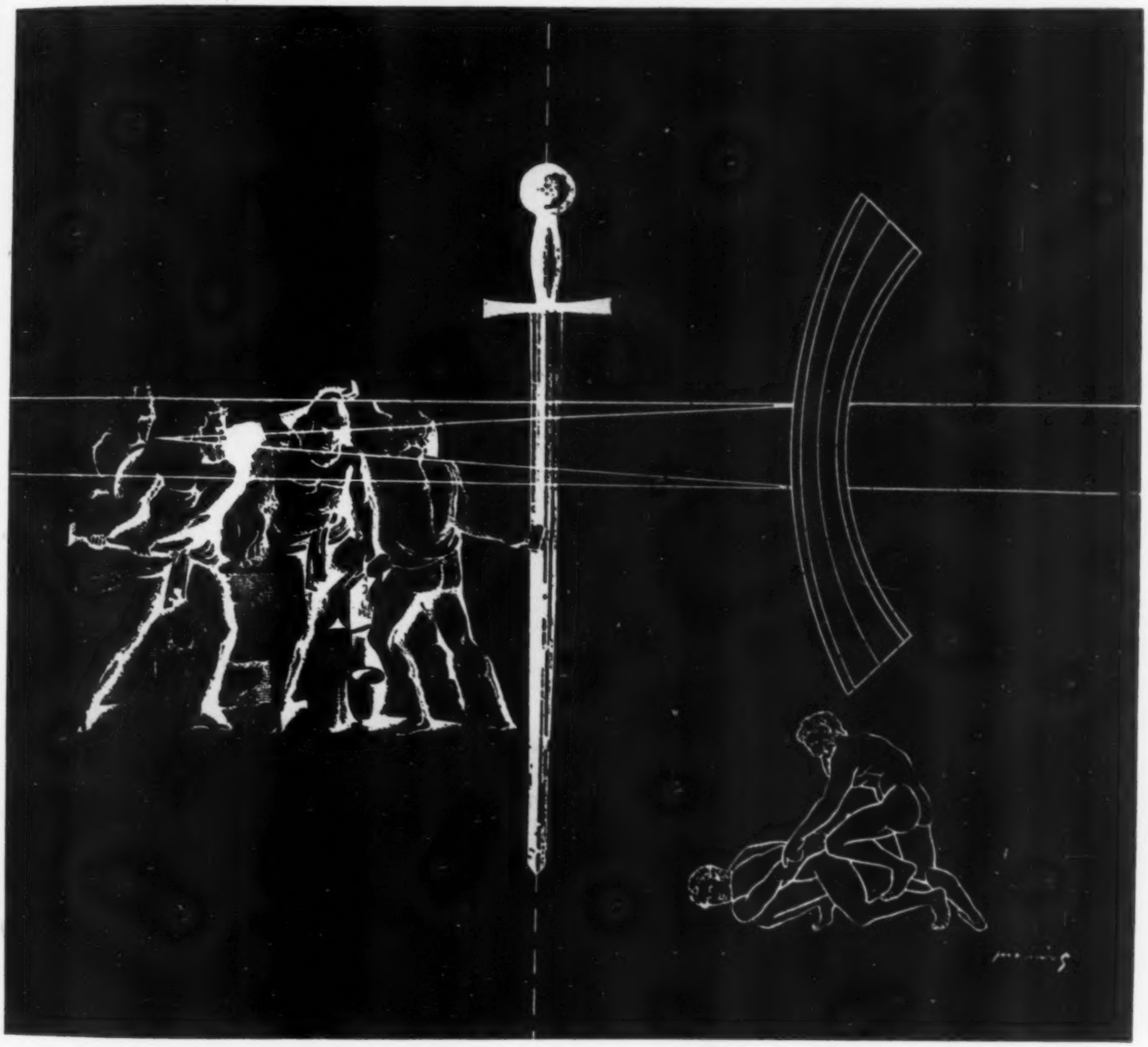
Hood Worthington, 43, chemical engineer for E. I. du Pont de Nemours & Co. at Wilmington, Del.

★Summarized in *Metal Progress* for May 1946, p. 992.

ONE CAME BACK

One of the legends surrounding the making of Damascus sword blades is that the smiths developed a delayed quench consisting of thrusting the heated blade into the body of a slave. This gave the required properties, but it was prodigal of manpower, and inconvenient besides. The smith usually had to leave town to do his heat treating in quiet.

Today, metallurgists can obtain properties they need in steel by simpler, less improvident means. A little molybdenum is one way of doing this. It is a proved means of obtaining the hardenability that assures good performance in service. Practical working data on molybdenum steels are available from Climax upon request.



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CLIMAX FURNISHES AUTHORITATIVE ENGINEERING DATA ON MOLYBDENUM APPLICATIONS.

MOLY

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PERSONALS

The Crucible Steel Co. of America has transferred **T. J. Phillips** ⊕ from metallurgist at the Sanderson Works, Syracuse, N. Y., to service engineer in Detroit.

After release from the Navy and graduation from the University of Illinois with an M.S. degree, **Ross M. Mayfield** ⊕ has joined the Du Pont Co. at the engineering experiment station, Wilmington, Del., as metallurgical engineer.

Earl O. Smith ⊕ has been transferred from the Carnegie-Illinois Steel Corp.'s Ohio works to the Vandergrift plant of the Irvin works as development metallurgist of silicon steels.

Bruce Bryan ⊕, formerly editor of *Western Metals*, is now editor and publisher of *The Drug Check Book*.

The Braeburn Alloy Steel Corp. announces the appointment of **Kenneth D. Bryan** ⊕ as general superintendent of their tool steel mill and **W. Rex Reiter** ⊕ as assistant general superintendent.

Robert B. Sosman, formerly at the United States Steel Research Laboratory, Kearny, N. J., is now professor of ceramics at Rutgers University, New Brunswick, N. J.

I. A. Usher ⊕, formerly chief metallurgist of the John Inglis Co., Ltd., has accepted a fellowship at the Ontario Research Foundation, Toronto, Canada.

L. B. Carlyon ⊕ has been appointed assistant professor, industrial education department, Kansas State Teachers College, Pittsburg, Kan.

John M. Capman ⊕ is now associated with the Kool-Vent Metal Awning Corp. of America as district sales manager of southern New Jersey, with offices at Long Beach Island, N. J.

Roland L. LeVaughn ⊕ has joined the metallurgical staff of the Vanadium Corp. of America at Niagara Falls, N. Y. He was discharged from the U. S. Army Air Corps in April 1946, and just concluded his postgraduate work at the University of Alabama.

William J. Craig ⊕ has become associated with the Cornell Aeronautical Laboratory, Buffalo, N. Y., as research metallurgist.

Logan L. Sumpter ⊕, formerly civil service tool and die hardener at Pearl Harbor Naval Air Station, is now with the Ingersoll Steel Div., Borg-Warner Corp., New Castle, Ind.

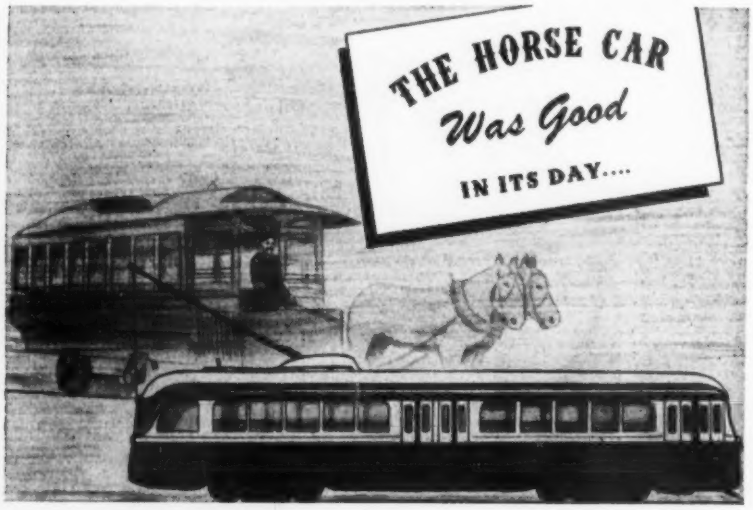
Herbert D. Groth ⊕, formerly with Brace, Mueller, Huntley, Inc., is now employed by the Firth-Sterling Steel & Carbide Corp., representing them in the Syracuse, N. Y., territory.

Jack W. Hobbs ⊕, formerly with the Goodyear Aircraft Corp., is now sales engineer for the Akron Welding and Spring Co., Akron, Ohio.

William J. Bradley ⊕ has been appointed foundry superintendent of Enterprise Foundry Co., Ltd., Sackville, N. B., Canada. He was previously foundry foreman of Dominion Engineering Works, Ltd., Montreal, Canada.

Theodore Goldberg ⊕, formerly metallurgist at the New York Naval Ship Yard, has become metallurgist, Crucible Steel Co. of America Research Laboratory, Harrison, N. J.

Richard Summers ⊕, formerly research engineer in the research and development division of Jones & Laughlin Steel Corp., is now with the Chase Brass and Copper Co. in the production department of the metal works division.



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- Deoxidine *
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AIR COMPRESSOR LUBRICATION

Solving AIR COMPRESSOR TROUBLES

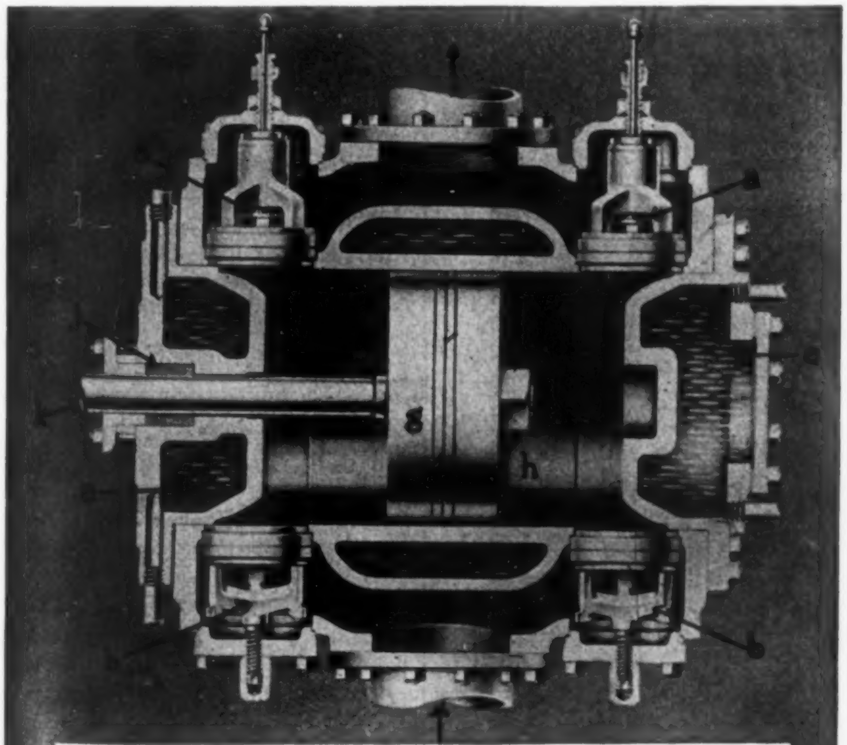
Lubrication Engineer's Report: "A mining company* in the Joplin area was having trouble with the unloading valve on an Angle Compound Air Compressor. They were also troubled with discharge valve breakage of the high pressure cylinder.

Case No. 1: "The previous oil was replaced with Cities Service North Star Oil No. 5 and not a single instance of gumming or sticking or trouble of any kind with the unloading valve or discharge valve has been reported in over two years."

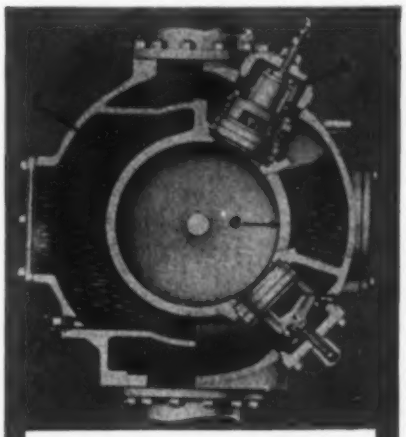
Case No. 2: "A utility plant* in Springfield, Mo., uses compressed air from a single stage belt-driven air compressor in connection with overhauling jobs of the boilers in their plant. They are all of the water tube type and are overhauled at regular intervals. During these overhauls they need a constant supply of air. The unloading valve of this compressor would gum up to the extent that they would have to clean it about every other day when using a competitor's oil. I sent them a drum of Cities Service North Star Oil No. 5 about a year ago, and checked with their Chief Engineer last month. He tells me they haven't had to clean the unloading valve since putting in the North Star Oil."

Case No. 3: "We have lubricated a 1000 cubic foot two-stage air compressor in the Mid-Continent area for over three years. The customer* says that in using Cities Service North Star Oil No. 5 in this compressor he hasn't had any valve breakage and that carbon deposit on valves and seats has been down to practically nothing."

**Names on request.*



a–Discharge valves • b–Intake valves • e–Water jacketed cylinder heads g–Piston • h–Cylinder wall • j–Stuffing box • k–Piston rod



a–Discharge valve • b–Intake valve • c–Cylinder • d–Cylinder jacket • f–Water surrounding cylinder

Solving compressor operating problems has been Cities Service's special forte for years. A phone call or card to the Cities Service office nearest you will bring this engineering experience to *your* plant. There is no obligation. For useful information that every air compressor owner and operator should know, write for our

Free Booklet: free booklet, "Air Compressor Lubrication." Cities Service Oil Co., Sixty Wall Tower, New York 5, N. Y., Room 112.

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New Electrode Welds Thin High Carbon Steel without Pre-heating

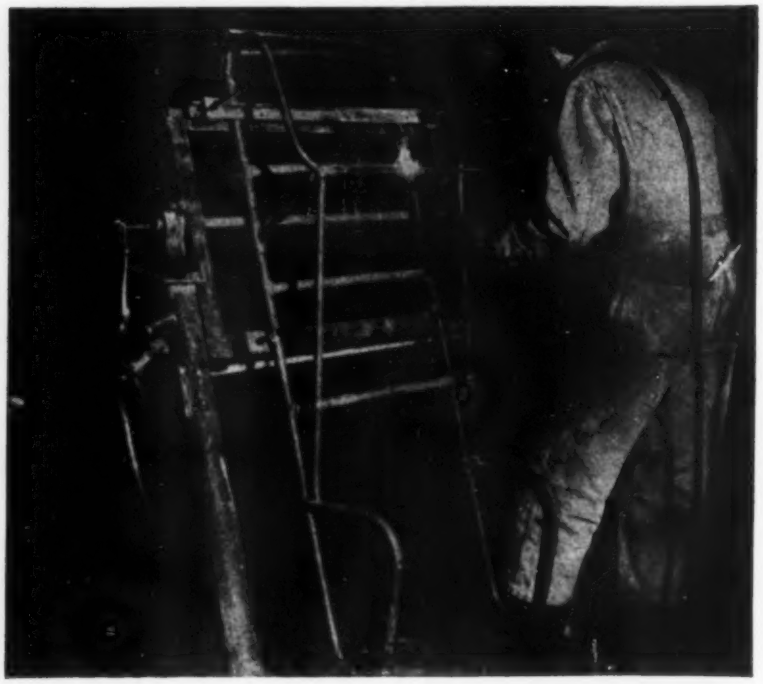
ORDINARILY considered difficult to weld, tubular high carbon steel with an exceptionally thin wall is being welded without pre-heating or special welding procedures by the Tubar Bending & Manufacturing Company, Cleveland, Ohio.

The product is the Tubar hand truck, a new design made entirely of SAE 1045 carbon tubular steel for strength and lightness. The tube walls are .076″. When the firm tried to set up production procedures, they experimented with conventional electrodes and found them unsatisfactory. Then they tried the new Lincoln "Shield-Arc LH-70" electrode, designed for difficult-to-weld steels, and found it gave good fusion without burn-through. No costly pre-heating or special procedures are needed.

Photo below shows the hand truck being finish-welded in a rotating jig that permits positioning for downhand welding. Jigs are used for both tack-welding and finish-welding to increase production speed and insure accuracy.

Description and procedures for "Shield-Arc LH-70" electrode will be sent free on request. Write The Lincoln Electric Company, Dept. 232, Cleveland 1, Ohio for a free copy.

Finish-welding the Tubar Hand Truck. Jig permits positioning for down-hand welding.



PERSONALS

Martin Kessler ⊕ has established a consulting service in Montclair, N. J., where he will serve as engineering and metallurgical consultant on die casting and other special manufacturing processes.

Ray R. Schumacher ⊕ has been transferred to Rochester, N. Y., representing Wheelock, Lovejoy & Co., Inc., in this area.

Victor A. Kortesoja ⊕ has been appointed tool trouble engineer at the Ford Motor Co., Dearborn, Mich. He was previously a student engineer there.

Morton C. Smith ⊕ has resigned from the faculty of the New Mexico School of Mines to become associate professor of metallurgy at the Colorado School of Mines, Golden, Colo., assuming his duties on Sept. 1, 1947.

R. H. Olmsted ⊕, formerly technical assistant at Farrel-Birmingham Co., Inc., Ansonia, Conn., has joined the Lake City Malleable, Inc., Ashtabula, Ohio, as laboratory supervisor.

Terminating his employment at Linde Air Products Co.'s research laboratory, **Arthur P. Siewert** ⊕ has joined the Central Foundry Div., General Motors Corp., Lockport, N. Y., as metallurgist.

Upon his discharge from the Army Air Force, **H. M. Clark** ⊕ has joined the Western Cartridge Co., East Alton, Ill., as assistant metallurgist in the research and development division.

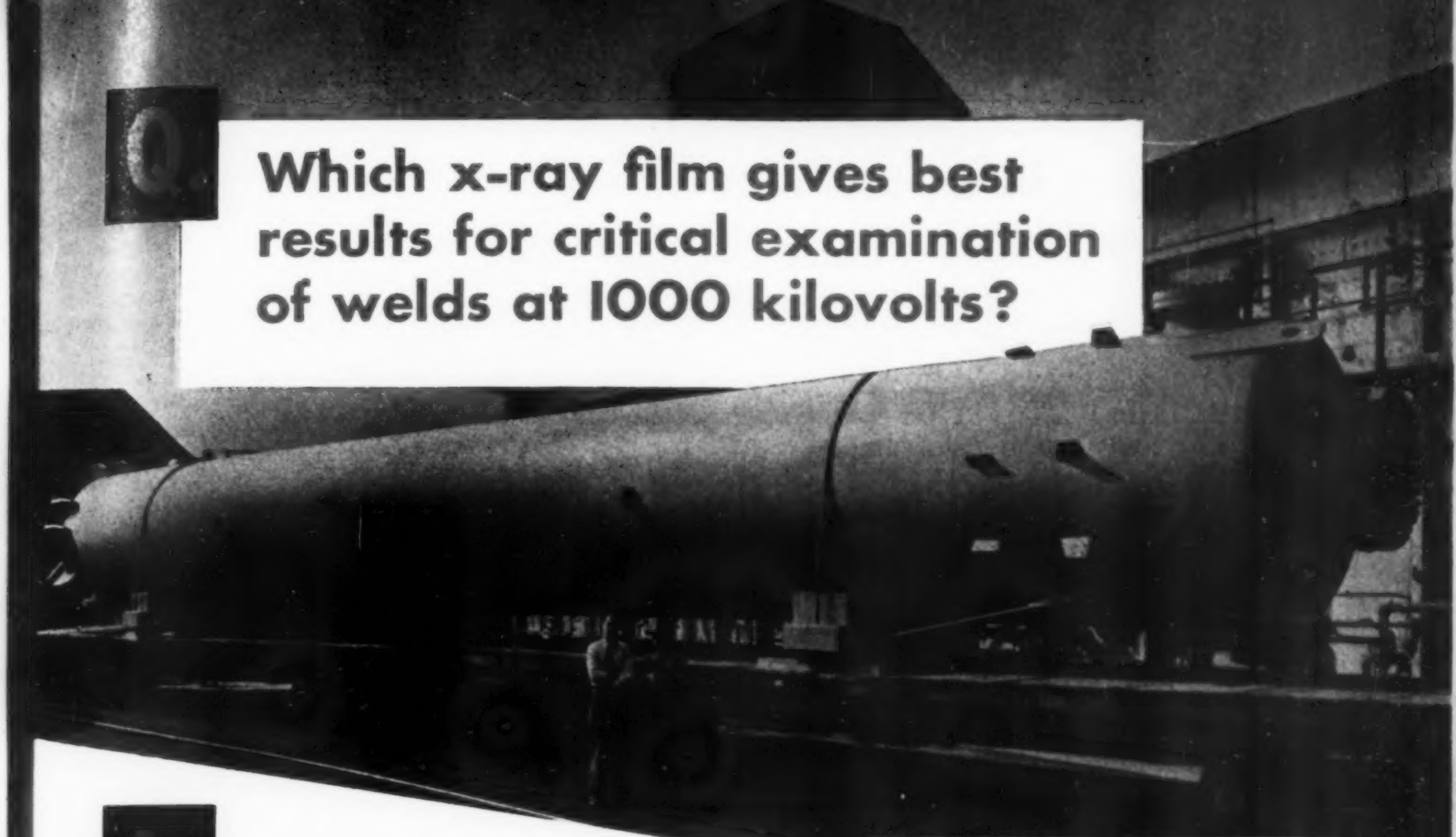
Julius M. Bleuenstein ⊕, formerly with the Beryllium Corp., has accepted a research position with Kerr Manufacturing Co., Detroit.

Alvin H. Barrows ⊕ has joined the sales personnel and organization division of Carnegie-Illinois Steel Corp., Pittsburgh.

On the dissolution of the partnership of Bendler and Dalzell, **Albert J. Bendler** ⊕ has taken over the consulting engineering service in New York City.

Ross C. Foltz ⊕ has joined the fittings division of the Ladish Co., Cudahy, Wis., as trainee in the sales department.

Sam T. Hamer ⊕, formerly senior inspector with the R. A. F. Transportation Command, Dorval Airport, Montreal, is now technical supply agent with Air France attached to Lockheed and Douglas aircraft plants.



Q.

Which x-ray film gives best results for critical examination of welds at 1000 kilovolts?

A.

KODAK's Type M

This manufacturer *knows* the welded seams of his high-pressure tank are sound.

How does he know? He has seen and studied the internal structure of those welds with radiography . . . using Kodak Industrial X-ray Film, Type M, with lead foil screens to do the job.

Why Type M? . . . Because short exposure time was not important—and because Type M, with its extra-fine grain and highest available contrast, makes possible radiographs that have exceptional detail and maximum sensitivity . . . both so essential in determining the soundness of welds.

But if short exposure time *had* been important? . . . Kodak Type A would have been the choice—because with its fine grain and equally high contrast it has considerably increased speed.

Radiography more than pays its way. To find out what radiography means to profits, just look around you, at other plants, other welding shops. You'll see how it enables them to prove the soundness of their welds quickly and thoroughly . . . how it guides welders to better technics . . . how it prevents costly failures and customer rejections.

Then—to find out exactly how radiography can do these same things for you—consult your local x-ray dealer, or write . . .

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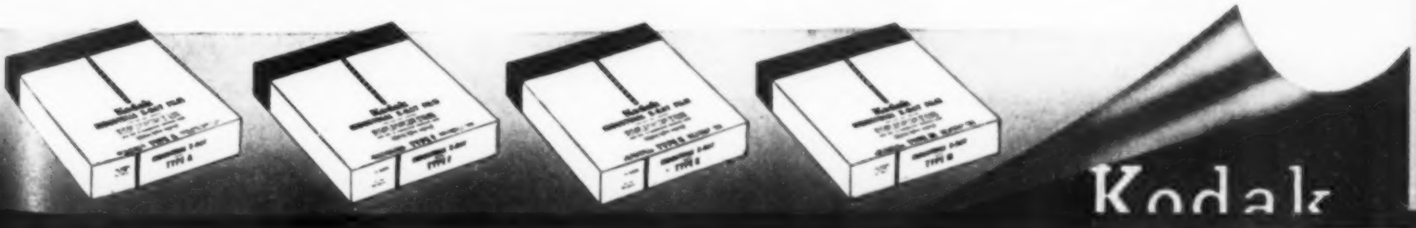
Inspecting radiographs of welds for nonhomogeneities

Other Kodak Industrial X-ray Films

Kodak Industrial X-ray Film, Type F . . . with calcium tungstate screens—primarily for radiography of heavy steel parts. The fastest possible radiographic procedure.

Kodak Industrial X-ray Film, Type K . . . primarily for gamma- and x-ray radiography of heavy steel parts, or of lighter parts at limited voltages where high film speed is needed.

Radiography... another important function of photography



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PERSONALS

Stephen Hujber, after being with the White Sewing Machine Co. for several months, has resumed his position as chief metallographer for the Marlin-Rockwell Corp., Jamestown, N. Y.

M. G. Whitfield and **V. Sheshunoff** have formed a partnership to continue their consulting work in the field of bonding aluminum to steel and other metals in Garden City, N. Y. They were formerly consultants and technical directors of the Al-Fin Corp., a subsidiary of Fairchild Engine and Airplane Corp.

V. D. Prian is staff engineer with Kenneth A. McIntyre Associates, Cleveland.

Maurice G. Steele was recently appointed vice-president in charge of engineering and research of the newly formed Kent Electric Corp. of Rome, N. Y., an affiliate of the Kent Co., Inc. Mr. Steele was formerly chief engineer for Kent Co.

The Koppers Co., Inc., announces the appointment of **Hugh C. Minton**, as production manager. He served in the Army Service Forces' production division during the War.

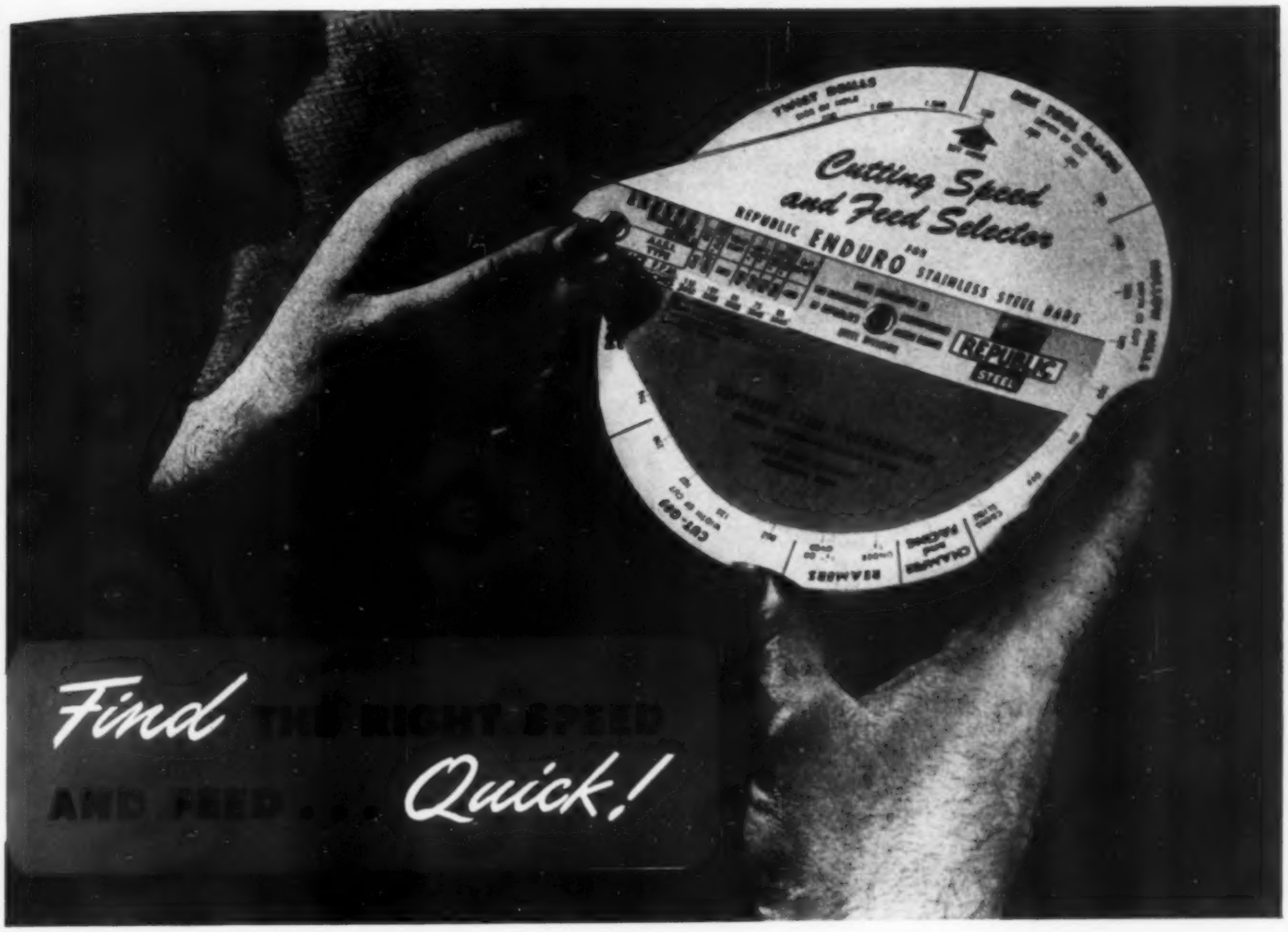
Edward Troy and **Edwin C. Sandham** have organized the Est Co., Grafton, Wis., for making permanent mold products of magnesium and aluminum.

The Jessop Steel Co., Washington, Pa., announces the appointment of **L. C. Grimshaw** as metallurgical engineer of the clad products division. Mr. Grimshaw was metallurgist and superintendent of clad steel division of Latrobe Electric Steel Co. previously.

Ernest V. Pannell, having terminated his connection with the British Aluminium Co., Ltd., has established a practice as consulting metallurgical engineer specializing in investigations and reports on light metals at Golvers Hill, Kingsteignton, England.

Jones & Laughlin Steel Corp. announces the appointment of **V. H. Lawrence** and **H. W. Graham** as vice-presidents. Mr. Lawrence was previously general superintendent of the Otis works, and Mr. Graham continues as director of technology in addition to being vice-president.

Ivan L. Nixon, previously manager of Bausch & Lomb's instrument division, has been elected a vice-president of the firm.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REPUBLIC ENDURO FOR STAINLESS STEEL BARS
REPUBLIC STEEL
Find THE RIGHT SPEED AND FEED . . . Quick!

WITH THIS NEW SPEED AND FEED SELECTOR FOR *Enduro* STAINLESS STEEL BARS

SEND FOR YOUR SPEED AND FEED SELECTOR—TODAY. You'll find it one of your most valuable aids in machining ENDURO Stainless Steel Bars. *AND IT'S FREE!*

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On the other side it gives spindle speeds in surface feet or revolutions per minute—together with the main chemical components of the machining stainless steels.

And for those who wish to hang it at their machines or drawing boards, it's punched and reinforced with a metal eyelet.

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Republic ENDURO Stainless Steel Bars, hot rolled or cold finished—also Wire—in a complete range of sizes and types.

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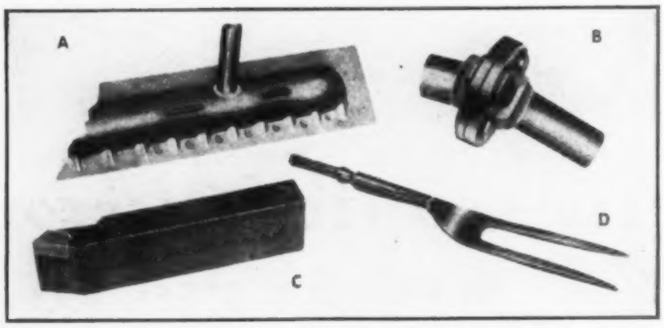
APW No. 217 is tops for low temperature production brazing of steel, stainless steel, alloy steel, copper, brass, bronze, Inconel and monel metal. Only small amounts are needed to make clean, sound, leak-proof joints.

Tested and approved by leading manufacturers... here are a few typical applications:



A-Stainless Steel & Copper Refrigerator Sub-Assembly. B-Brazed Steel Universal joint. C-Carbide Tool Tip brazed to Shank. D-Stainless Steel Fork Assembly.

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PRECIOUS METALS SINCE 1875

HIGHEST GRADE STEEL CASTINGS*

NO PRACTICE that is standardized, in the true sense of the term, exists in the melting of acid steel for castings. While steel scrap, low in phosphorus and sulphur, is ordinarily charged into the furnace, the acid process is distinctly a process of *making* steel, and not simply one of melting. However, the four phases of the operation vary much from shop to shop. For example, the requirements for an adequate "boil" for reducing the carbon are considerably disputed. Methods and materials for deoxidation vary; some melters deoxidize first with silicon; others with manganese; still others with a combination; some deoxidize as soon as possible; others as late as practicable. Next, the $FeO:SiO_2$ balance (necessary for correct fluidity of slag) must be controlled for each individual heat by coordinating additions, heat input, and sequence of operations. Final deoxidation is the most uniformly done; an optimum quantity of aluminum, added in the ladle, is almost universal.

In view of this multitude of variables, information on commercial practice must come from a study of a large number of heats of the same type of steel. Such a study was made on 120 heats of 0.25% C, 0.65% Mn, and 0.45% Si. Their quality was appraised by the "P-factor", used frequently in the automotive industry, figured from

$$P = \frac{T.S. + 6000\ R.A.}{5000},$$

where T.S. is tensile strength and R.A. is reduction of area.

P for the ten best heats ranged between 77.8 and 84.6† and for the ten poorest between 43.4 and 61.9. The most significant variation in the heat records was the predominance of certain deoxidation methods among the best heats (maintaining a relatively oxidizing bath throughout the heat and deoxidizing by simultaneous addition of silicon and manganese to the bath shortly before the tap), and

(Continued on page 994)

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*Abstracted from "Acid Electric Steel for Castings", by Sam F. Carter and C. K. Donoho. Electrochemical Society Preprint 91-12, 1947.

†This is exceptionally high for this type of steel. Five A.S.T.M. and Federal specifications permit tensile properties which figure P = 49 to 58, so even the "poor" heats described by the authors would all but one be acceptable.

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[illegible]

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Save large furnace equipment for the big jobs . . . use COOLEY Electric Furnaces for accurate and economical heat treating of *small parts.*

When you have a COOLEY, there is no need to wait for large furnace time or use the power required to heat such a furnace. Always-ready COOLEY Furnaces give you convenient capacity for small work, together with highly accurate temperature control, simplicity of operation, unusual flexibility and an operating cost as low as 4¢ per hour. These efficient box furnaces are now available in 11 types and sizes to offer the correct model for your requirements *(see table below).*

2 TYPES OF AUTOMATIC CONTROL

For hardening and other *high temperature work* to 1850° F., MH and VH model furnaces are for use with indicating and controlling pyrometers, mounted separately or as part of a factory wired panel and stand integral with the furnace.

For precision control of heating from 300° to 2000° F., including *low temperature applications* such as tempering or drawing of steels, non-ferrous heat treating, etc., MK and VK model furnaces are equipped with a **Selective** Power Modifier to supplement the controlling pyrometer. This combination corrects the characteristic lag of chamber temperatures behind the pyrometer reading to as low as 300° F., and eliminates low temperature overshooting.

USE COOLEY FURNACES FOR:

- **Metallurgical Laboratory Heat Treating.**
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- **Pilot Runs to Establish Procedures and Scheduling.**
- **Production Heat Treating of Small Parts — Normalizing, Annealing, Hardening and Drawing.**
- **Hot Forming Steel; Enameling; Glass Annealing.**
- **Emergency Repairs and Maintenance.**

CHAMBER	8"W 6"H 14"L				10"W 6"H 18"L				8"W 6"H 14"L
MAX. TEMP.	1850° F.				1850° F.				2000° F.
AMPERES	14.8 at 230 v.				19.6 at 230 v.				20.2 at 230 v.
WATTS	3400				4500				4650
MODEL*	MH-3	VH-3	MK-3	VK-3	MH-4	VH-4	MK-4	VK-4	VK-5
PRICE	146.00	166.00	186.00	206.00	222.50	242.50	262.50	282.50	340.00

* M models complete with hinged door and hearth plate.
V models have counterweighted vertical lift door with adjustable opening.
K models include Selective Power Modifier for input control to correct temperature lag.

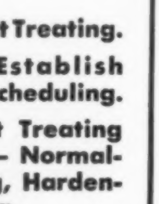
FORCED CIRCULATION AIR DRAW FURNACES — Write for data.

ACCESSORY EQUIPMENT

Electronic operated Veri-Tron indicating and controlling pyrometer, with thermocouple and lead wire	$143.00
Same in self-contained, enclosed panel including line switch and fuses, with steel stand—completely wired	240.00
Steel stand with shelf	35.00

FREE LITERATURE

NEW CATALOG completely describes all models and applications for each. Write today for your copy . . . no obligation.



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Export Manager 44 Whitehall Street, New York, New York

STEEL CASTINGS

(Continued from page 992)

— contrariwise — the prevalence of other sequences among the poorer heats (blocking with silicon or manganese some time before tapping).

To obtain the highest tensile quality the following suggestions as to furnace practice are presented from an analysis of the data:

1. Keep the melt-down at least slightly oxidizing to minimize the possibility of gas absorption and maintain efficient arcing.

2. As soon as melted, establish a high concentration of iron oxide in relation to lower residual silicon and manganese, thus imparting maximum fluidity to inclusions, and reducing the solubility for hydrogen.

3. Provide a melt-down carbon high enough to permit a considerable carbon drop and cause evolution of carbon monoxide gas over a sufficient period of time to flush out all rejected gases and inclusions and prevent atmospheric gases from re-entering the bath.

4. If previous conditions have been met, no advantage seems to be gained from forcing the carbon lower than 0.20%.

5. Keep the slag moderately oxidizing and the heat open and slightly boiling as long as practicable while the carbon is being adjusted and the slag is being shaped up. Slightly poorer physicals result if slag FeO gets too low or if the heat is deoxidized too early.

6. For the first deoxidant, a combination of manganese and silicon proved better than either element alone.

7. If for reasons of chemical control a silicon block is advisable, it can be used with a negligible sacrifice of tensile quality if the minimum addition is made under a moderately oxidizing slag, and no earlier than about 5 min. before tap.

8. The manganese and silicon should be added in time to complete their deoxidation reactions before aluminum is introduced, in order to minimize the quantity of aluminum oxide inclusions.

9. Slag control should be directed toward a final condition of intermediate fluidity and FeO content. Both oxidizing and reducing extremes proved detrimental from the standpoint of ductility and tensile quality.

(Continued on page 996)

This WHEELABRATOR cleans 100,000 heat treated drills and cutters WEEKLY

CLEANING PROBLEMS SOLVED...

With production of a large variety of carbon and high-speed drills, taps, cutters and reamers greatly increased, the Union Twist Drill Co. found that its airblast cleaning equipment was inadequate. Besides, many of these products could not be cleaned economically in existing equipment.

The installation of a 6′ PLAIN WHEELABRATOR TABLE for removing scale from the larger tools, and a 20″ x 27″ WHEELABRATOR TUMBLAST for handling the smaller pieces, satisfactorily solved the problem.

The TABLE cleans more than 100,000 pieces weekly . . . and the TUMBLAST cleans loads containing 1000 to 2000 pieces in ten minutes, whereas formerly more than four hours were required. Thorough scale removal has not only improved the appearance of all products but grinding time has been reduced as well.

Write for our free 20-page illustrated booklet, "CLEANING PROBLEMS SOLVED in the Heat Treating and Forging Industry." Contains complete case history data, comments from users, photos of Wheelabrated products, installation views and types of equipment recommended in this field.

TYPICAL PRODUCTS CLEANED

Gears • Springs • Crankshafts • Bearings • Cutlery • Chain • Drill bits • Axles • Pliers • Lockwashers • Saws • Files • Dies • Connecting rods • Shafts • Wrenches • Wheels • Shovels • Piston pins • Plowshares • Hammers • Tool bits • Reamers • Chisels • Axes • Rakes • Rifle parts • Knives • Sprockets • Pinions • Splines • Torsion rods.

TYPICAL USERS OF THE WHEELABRATOR

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AJAX
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ELECTRIC FURNACES
for the ALUMINUM ALLOY
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THE AJAX-Tama-Wyatt Low Frequency Induction Furnaces are now made in small sizes with capacities ranging from 20 to 35 kw.

Their operation is based on the induction principle whereby energy is transmitted to the molten charge without actual contact, through the refractory walls. Only the metal is heated, and therefore, there are no resistors or other parts having a higher temperature than is absolutely necessary for properly melting the charge. A gentle movement of the bath insures uniform temperature and homogeneous mixing of the alloy ingredients. Linings are made of inert refractories which do not contaminate the melt.

These melting machines are delivered with self-contained, completely factory wired control cubicles, including automatic temperature controllers.

AJAX ENGINEERING CORPORATION, Trenton 7, N. J.

AJAX
TAMA-WYATT
INDUCTION MELTING FURNACE

AJAX METAL COMPANY, [illegible]
AJAX ELECTROTHERMIC CORP., [illegible]
AJAX ELECTRIC CO., INC., [illegible]
AJAX ELECTRIC FURNACE CORP., [illegible]

STEEL CASTINGS

(Continued from page 994)

Lastly comes the problem of final deoxidation — usually aluminum in the ladle. If 2 to 2½ lb. of metallic aluminum is added per ton and 0.02 to 0.03% remains in the steel as metal (not oxide), few pinholes exist in castings poured in sand molds. Steels *without* aluminum may be cast in metal molds or thoroughly dried sand molds with no pinhole porosity. Such aluminum-free steels are coarse grained; likewise they are about five percentage units higher in elongation in the tensile test. Castings for use at high temperature may also be specified as aluminum-free, because of aluminum's supposed influence on graphitization of the carbides. Chromium steels with more than 6% chromium are free of pinhole porosity, even without aluminum in the ladle. ●

NONCORRODING STRUCTURES*

IN DESIGNING equipment, first consideration is usually given to mechanical requirements. Of all the factors that are functions of time, corrosion is probably the most difficult to take into account. Nevertheless, certain fundamental precautions can be incorporated.

It is common practice to figure corrosion at a uniform rate, but the occurrence of localized attack, resulting from metallurgical structure or conditions of exposure, often makes it difficult to evaluate the true extent of corrosion damage. It is frequently necessary to consider the effect of corrosion on the products being handled even though the attack is insufficient to cause structural damage. Contamination is to be avoided in handling food products. In other cases, certain materials may catalyze the decomposition of the product being handled.

The possibility of galvanic action between dissimilar metals is now rather widely known, but it is not such common knowledge that the potential of any metal

(Continued on page 998)

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*Abstracted from "Designing to Prevent Corrosion", by R. B. Mears and R. H. Brown. *Corrosion*, V. 3, March 1947, p. 97 to 118.

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NONCORRODING STRUCTURES

(Continued from page 996)

depends on environment. It is good design to avoid the use of dissimilar metals in contact. When dissimilar metals must be used, special precautions should be taken to prevent or alleviate galvanic corrosion. If dissimilar metals are employed in complex equipment exposed to moisture, complex cell action may occur even though the dissimilar metals are insulated. It is fortunate that the resultant corrosion is generally milder than that caused by direct contact between dissimilar metals. Yet, despite complete insulation of dissimilar metals and the absence of complex cells, the ions of one metal may accelerate the corrosion of the other.

The most obvious method of eliminating galvanic corrosion is to use only one material but this is not always feasible. Combinations can be selected which develop little galvanic action. Alternatively, direct galvanic effects can be prevented by complete insulation of the dissimilar metals. Painting or plating may be helpful. Strips of a third metal, if selected and attached properly, will cathodically protect both members.

Contact with nonmetallic materials frequently causes very severe attack of metals. Some nonmetallic materials contain soluble, highly corrosive constituents. Other nonmetallic materials may retain moisture or may cause oxygen concentration cells. This type of corrosion can be prevented by selecting materials known to be relatively innocuous or by preventing the wetting of the nonmetallic materials. Painting or the use of suitable adhesives to attach the nonmetallic material may help.

It is good practice to eliminate crevices and low spots where water will be trapped. Joints are likely to be particularly susceptible to corrosion. In certain applications, all areas of the dissimilar cathodic member can be plated with a coating of a metal with the same potential as the anodic material. In joints of dissimilar metals it is desirable to use as small a surface area of the cathodic member as possible. Sometimes a sacrificial piece of a third metal can be added adjacent to the joint to protect the anodic material.

(Continued on page 1000)

Facts about Hoskins Type FR Box Furnaces

Type No.	K. W. Rating	Heating Element	†Hrs. To Reach 1500°F.	K. W. To Hold At 1500°F.	††Cap. In Lbs. Of Steel Per Hr. at 1500°F.
FR-206	13	Chromel	1¼	3.2	75-100
FR-207	16	Chromel	1½	4.1	100-200
FR-208	19	Chromel	1½	5.0	120-240

†Approx. time required after 12-hr. shutdown from 1500°F. for furnace to become thoroughly soaked and ready for use again at 1500°F.

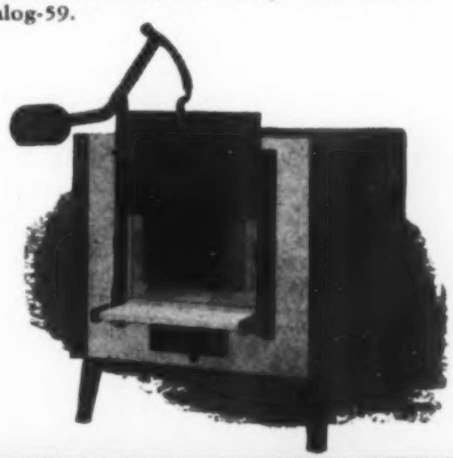
††Small figures apply to tool work according to std. practice; large figures are maximum production with full power, no soaking period.

HUSKY Hoskins Box Furnaces . . . Types FR-206, 207 and 208 . . . are electric "standards" designed to meet the requirements of many varied heat-treat operations. Operating directly on the line, A.C. or D.C., at 110 or 220 volts, they have a normal temperature range up to 1850°F. with a maximum of 2100°F. on certain approved applications. Heating elements are made of CHROMEL . . . *durable CHROMEL ribbon* . . . located on all four sides of the box and designed especially to provide a fine uniformity of heat distribution throughout the furnace. They slide freely in and out of refractory supports and can be quickly, easily renewed whenever required.

Our Catalog-59 contains facts . . . complete facts on these and other dependable Hoskins furnaces. Want a copy?

LABORATORY FURNACES

Typical of the Hoskins laboratory line is the Type FD Muffle furnace shown below. It operates on A.C. or D.C. at usual line voltages and has a temperature range from 1200°F. to 1800°F. Insulation 4½" thick keeps heat in, conserves power. Equipped with heavy gauge CHROMEL heating element to assure long and trouble-free service. Fully described in Catalog-59.



HEATING ELEMENT WIRE
Chromel
NICKEL CHROMIUM

HOSKINS MANUFACTURING CO.

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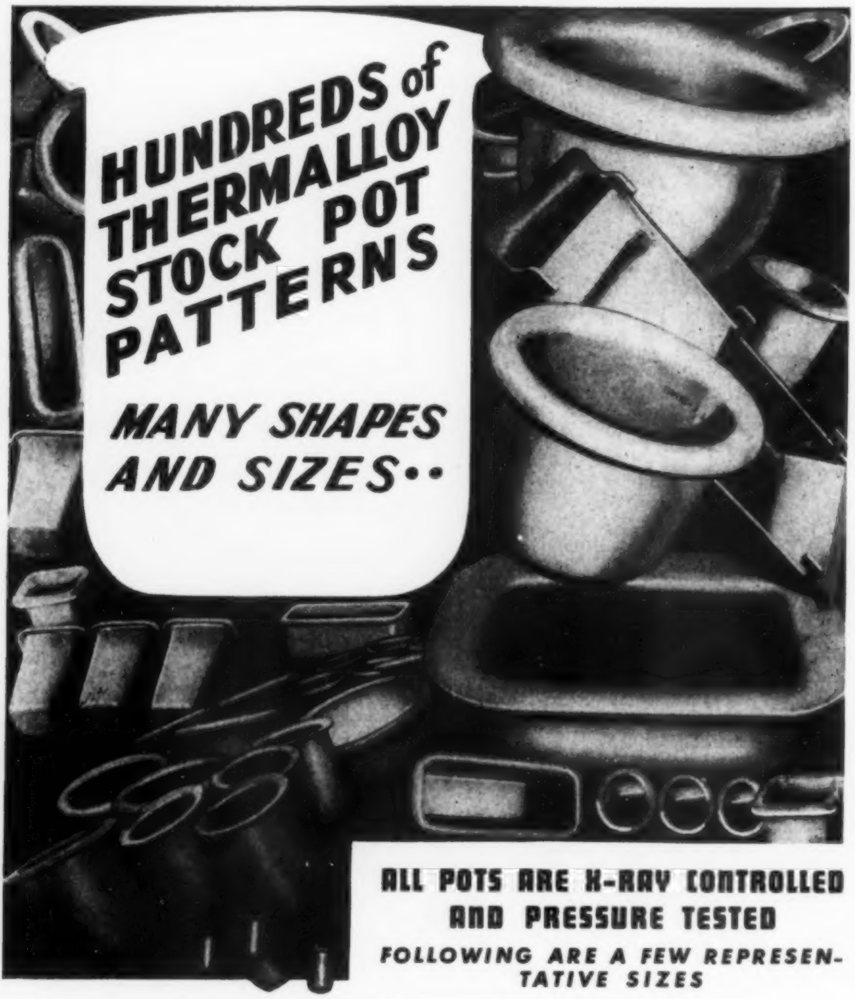
ELECTRIC HEAT-TREATING FURNACES • HEATING ELEMENT ALLOYS • THERMOCOUPLE AND LEAD WIRE • PYROMETERS • WELDING WIRE • HEAT-RESISTANT CASTINGS • ENAMELING FIXTURES • SPARK PLUG ELECTRODE WIRE • SPECIAL ALLOYS OF NICKEL • PROTECTION TUBES

*TRADE MARK REG. U. S. PAT. OFF.



ALL POTS ARE X-RAY CONTROLLED AND PRESSURE TESTED

FOLLOWING ARE A FEW REPRESENTATIVE SIZES

SIZES SHOWN IN INCHES

6 x 8
6 x 12
6¾ x 7
8 x 8
8 x 10
8 x 12
8 x 14
8 x 18
8 x 31
8¾ x 10
8¾ x 10⅝
9¾ x 17⅝
10 x 10
10 x 12
10 x 12
10 x 14
10 x 16
10 x 18
12 x 11
12 x 12
12 x 14
12 x 16
12 x 18
12 x 20
12 x 24
12 x 30
12 x 64
12 x 32
12¾ x 14
14 x 12
14 x 14
14 x 16
14 x 18
14 x 20
14 x 24
14 x 30
14 x 32
14 x 36
16 x 14
16 x 16
16 x 18
16 x 20
16 x 24
16 x 27
16 x 30
16½ x 17
17⅝ x 12
18 x 14
18 x 18
18 x 20
18 x 24
18 x 30
19 x 15
19 x 16
19 x 34
20 x 15
20 x 17
20 x 20
20 x 30
20 x 34
20 x 80
20½ x 24
24 x 20
24 x 30
24¼ x 24
24¼ x 24¾
25½ x 24
27¾ x 38⅛
28 x 24
29 x 20
29 x 23⅜
30¾ x15⁷/₁₆
33⅛ x 21
36 x 30
36 x 36
38¾ x 40
41½ x 32

When you order your THERMALLOY pot from stock patterns, you save money and valuable replacement time. The chances are good we have a pot size to fit your furnace.

All pots are X-RAY controlled and pressure tested—100% X-RAY inspection available.

AMSCO ALLOY and THERMALLOY are identical

AMERICAN
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COMPANY

ELECTRO-ALLOYS DIVISION

ELYRIA, OHIO.

NONCORRODING STRUCTURES

(Continued from page 998)

Even when both members are of the same metal, joints are often more likely to corrode than the rest of the equipment. The joint surfaces may be primed or a calking compound used.

Cathodic protection by an external electric current is generally feasible only when the corrosion is caused by an electrolytically conducting liquid. Of most importance is the use of either noncorrodible anodes or low cost anodes, either of which must not polarize sufficiently to reduce greatly their current carrying capacity. Anodes of graphite, carbon, iron, steel and aluminum have been used commercially.

Galvanic zinc anodes have been most widely used in the past to protect steel or aluminum structures. Magnesium and aluminum alloy anodes are now coming into the field. Galvanic anodes have the advantage of being easier to install, and they do not require as much maintenance as the application of external current.

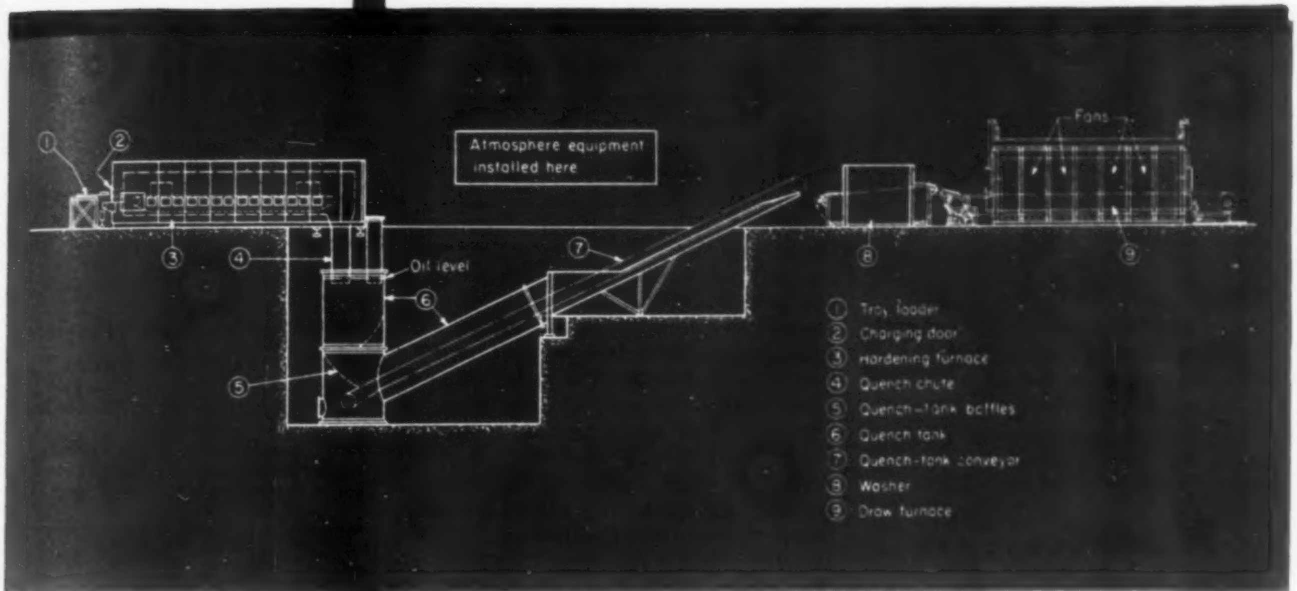
Certain metallic coatings give cathodic protection to the base metal under many conditions of service. Familiar examples are galvanized steel and alclad aluminum alloys. Coatings of metals which are cathodic to the base metal will accelerate attack of the base metal unless the coatings are absolutely continuous.

Corrosion is usually more likely to occur at inaccessible areas than on freely exposed surfaces which are kept clean by use or frequent cleaning. It is therefore good design to avoid crevices or to use special protection at inaccessible areas. Where complete sealing is not feasible or where the equipment is used intermittently, it is advisable to provide ventilation. Tanks and chemical equipment should be designed so that they can be drained completely. Although periodic cleaning will not always prolong useful life, it will help to do so in many instances. If it is not possible to design equipment to last indefinitely, it should be constructed so that parts which fail can be readily replaced.

Corrosion inhibitors can frequently be employed economically in closed systems. Chromates are the most effective common inhib-

(Continued on page 1002)

How to put 4 HEAT-TREATING OPERATIONS on a "PRODUCTION-LINE" BASIS



The accuracy of this "packaged" heat-treating process improves quality and uniformity—*eliminates* scaling and cleaning, materially reduces rejects.

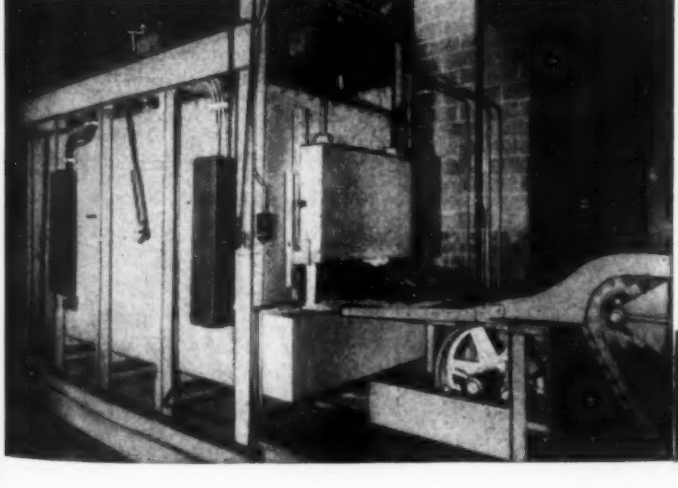
COMPLETE, conveyorized electric heat-treating equipment for hardening, quenching, cleaning, and drawing in a single, continuous operation— this automatically controlled equipment makes possible improved heat treatment of automotive or similar parts of various shapes and sizes, in large volume, much more rapidly, and at less cost. A non-decarburizing furnace atmosphere is provided by a G-E Neutralene producer.

From the belt-conveyor hardening furnace (No. 3 in above diagram), parts drop directly into the deep quench tank, especially designed to prevent distortion and nicking. The quench tank conveyor (No. 7) then carries the parts to the washer (8), from which they go directly to the draw furnace (9)—***all*** without handling.

Precision control of the entire process, accurate to a degree possible only with ***electric*** heat, improves uniformity and quality to the point where scaling is eliminated and rejects are sharply reduced in number.

Whether your requirements involve such a *complete* heat-treating process or smaller, individual furnaces, General Electric builds experienced-proved electric furnaces in a wide range of sizes and ratings for hardening, drawing, annealing, enameling, brazing, malleablizing, normalizing, and laboratory work. Our heating specialists and application engineers are prepared to recommend the electric heating equipment most suitable for *your* process; just contact the nearest G-E office. *Apparatus Department, General Electric Company, Schenectady 5, N. Y.*

From the washer, parts are loaded directly into the charging end of the mesh-belt-conveyor drawing furnace. This complete, conveyorized equipment produces uniformly heat-treated parts much more rapidly, and at lower over-all cost.



GENERAL ELECTRIC

NONCORRODING

(Continued from page 1000)

itors but considerable information is required to determine whether their use is justified in any specific case. Where an absorptive nonmetallic material will be in contact with a metal in the presence of water, impregnation of the nonmetallic material with a suitable inhibitor may help prevent serious corrosion.

ANALYSIS BY ELECTRICAL RESISTIVITY*

IT IS believed by the authors that spectrographic analysis of light alloys is not sufficiently accurate to justify its extended use in estimating the alloy content of alloys such as D.T.D. 300 (aluminum with about 10% Mg) and D.T.D. 59A (magnesium with about 8% Al). Density and electrical resistivity are alternative physical properties which might be suitable for a rapid method of analysis.

Density measurements on chill-cast specimens of D.T.D. 300 showed a poor correlation with the magnesium content because of the presence of porosity. No further work on density was done as electrical conductivity proved to be 15 times more sensitive to composition changes.

Electrical resistivity measurements were made on cylindrical specimens machined from test bars cast in an iron mold and not subsequently heat treated. It was found that the results depended on porosity, microstructure and casting procedure. Resistivity measurements were too high with unsound specimens. Mold temperature and the time in the mold before stripping were factors of casting practice that had an important effect upon resistivity results. With careful control, a straightline relationship between alloy content and resistivity could be obtained.

(Continued on page 1004)

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*Abstracted from "A Rapid Method for the Analysis of Light Alloys, Based on Electrical Resistivity", by L. Rotherham and J. I. Morley. *Journal* of the Institute of Metals, V. 73, Part 4, 1946, p. 213 to 222.

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FOR INDUSTRIAL HEATING

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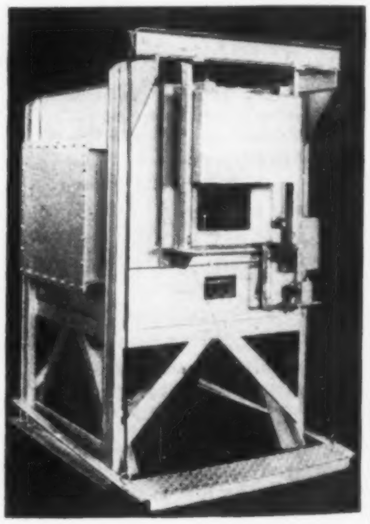
QUESTIONS AND ANSWERS ABOUT
Harper
ELECTRIC FURNACES

7. Who builds Harper Electric Furnaces?

Harper Electric Furnaces are individually designed by engineers who have specialized on high temperature electric furnace construction for many years.



A thorough knowledge of the importance of correct balance between heating elements, refractories, temperature control and other requirements for uniform, accurate temperatures results in satisfactory performance. Harper Furnaces are built in a wide range of types, sizes and capacities for industrial, laboratory and school uses. Write for data.

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ELECTRIC FURNACE CORPORATION
1450 Buffalo Ave.
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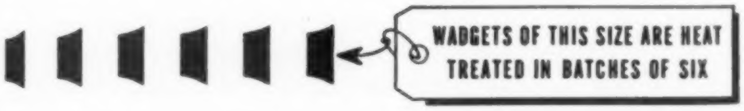
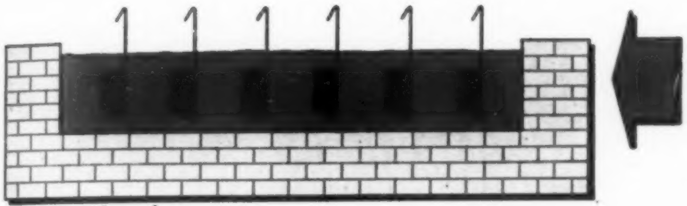
HOW TO HEAT TREAT A WADGET*
AT *LOWEST COST*

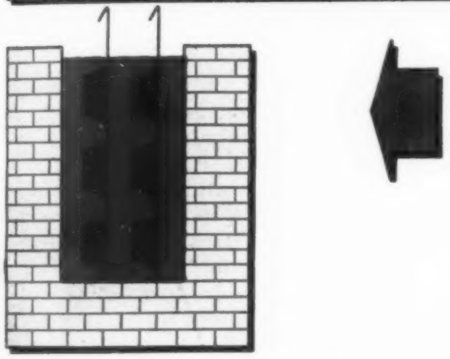
To protect the surface, avoid distortion, eliminate decarburization, a salt bath furnace will, of course, be used


WADGETS OF THIS SIZE ARE HEAT TREATED IN BATCHES OF SIX



If you get a *conventional* salt bath furnace it looks somewhat like this . . . and the Wadgets are placed like this.

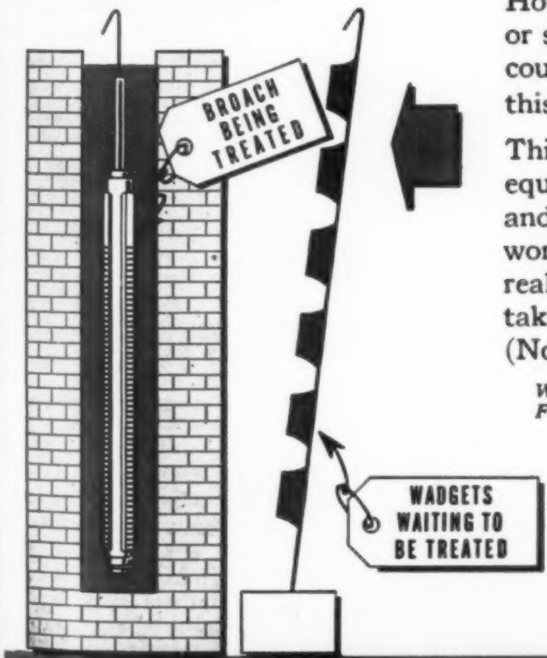
Note the surface area exposed†



If you have an *Upton* Electric Salt Bath Furnace it would probably look like this . . . with the Wadgets being placed like this.

Note surface area exposed†

†Surface radiation losses equal 15 KW per sq. ft. per hour.



However, if you also wanted to treat a broach or some similar long piece of work, then you could use an Upton Furnace that looked like this.

This saves more heat (and more power), does equally good work, takes less time loading and unloading, but some people think it won't work; that it's too deep. So, until they do realize that Upton Furnaces can be built to take any length work, the other furnace (No. 2) is usually supplied.

Why don't you send for more information on Upton Furnaces? Send us the dimensions of your Wadgets.

* Wadget: A piece of work that you are wondering how to treat for better results and at lower cost than at present which will eventually be heat treated in an Upton Electric Salt Bath Furnace because there is no known size or shape that cannot conceivably be treated in an Upton Electric Salt Bath Furnace

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ANALYSIS

(Continued from page 1002)

With this method, a change of resistivity of 0.53 microhm-cm. for 1% of magnesium was obtained in the D.T.D. 300 type alloys containing 9 to 11% Mg, where the alloys were made of 99.7% pure aluminum and commercially pure magnesium or scrap of similar deviation. The "standard deviation" of a series of determinations was 0.16% Mg. For the magnesium alloys of the D.T.D. 59A type, where the purity corresponded to that of virgin ingot material, a slope of 0.75 microhm-cm. was found, the corresponding standard deviation being 0.13% Al. In the latter alloys, however, it may be necessary to re-establish the correlation for each batch of raw material if the zinc and manganese contents differ appreciably.

These actual relationships are applicable only to the standard casting procedure adopted. Any suitable technique may be standardized, provided that a new correlation is established. Once this is done, a periodical chemical analysis is all that will be required to check the consistency of the sampling procedure.

It is suggested that these relationships offer the possibility of an extremely rapid method of foundry analysis control, as, with simple equipment, electrical resistance can be quickly measured with a high degree of precision. Under suitable conditions, the accuracy of the method would be greater than that of the accepted spectrographic methods. ⊕

PRESSURE WELDING OF ALUMINUM*

PRESSURE welding of aluminum combines the two processes of forming in a hot condition and welding. It is particularly suitable for large quantities. Where no forming is required, any undesirable buckling must be prevented by use of compressed air or some other means. *(Cont. on page 1008)*

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*Abstracted from "Pressure Welding — Manufacture of Light Alloy Charge-Cooler Element", by H. Herrmann. *Metal Industry*, Feb. 22, 1946, p. 143 to 147. (Translated from the German.)

HOW TO SOLDER POLISHED BRASS

Without discoloration

2 JOINTS IN 5 SECONDS

WITH HIGH-FREQUENCY HEATING

Moeller Instrument Company, manufacturers of precision temperature-indicating devices, had this problem: how to solder two joints of this thermometer case without discoloring the highly polished brass. Solution was found in high-frequency heating, using a Lepel converter which is fully effective on non-ferrous as well as ferrous materials.

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A production set-up for this operation is illustrated. With a 30-kw converter, four-position load coils can be used. With pre-formed solder rings and a change-over switch, soldering can be practically continuous — 3500 or more complete cases per day per operator. No skill is required to produce perfect joints, since timing is automatic. Working conditions are clean and cool, ideal for locating on any production line.

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BRAZING
HARDENING
ANNEALING
MELTING

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WELDING OF ALUMINUM

(Continued from page 1004)

The process has been developed for airplane engine cooler parts which are press welded from a flat sheet 0.016 in. thick, and formed by compressed air while hot. The alloy used is known as Pantal; it contains 0.79% Mg, 1.10% Si, 0.85% Mn, 0.39% Fe, 0.02% Ti, 0.13% Cu, 0.15% Zn, 0.05% Ni, balance Al.

The dies used in production of charge-cooler elements are made of toolsteel containing 1.9% C, 0.5% Mn, 0.5% Si, 12.3% Cr and 0.15% V. The two thin aluminum alloy sheets are laid cold, one on the other, between two hot welding "teeth". The temperature at which the aluminum is pressure welded varies between 790 and 895° F., according to the alloy, while the pressure varies from 4255 to 11,425 psi. For annealed aluminum it is low; for Pantal it is of the order of 7170 psi. Gas burners are used with heat resisting steel blocks to heat the welding dies. They can also be heated electrically, with silicon carbide rods preferred. However, gas is most reliable. Water-cooled plates protect the press against undesirable heat. The outer tooth of the dies and their two ends have an insulation of asbestos and sheet metal, which is important for uniformity of welding. Various types of hydraulic and toggle presses can be used but the latter has proven most satisfactory. Time for the production of a welded part is about 30 sec.

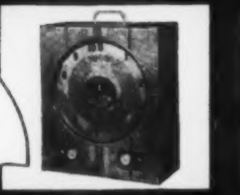
The strength obtained in a reduced cross section of the material is dependent on the degree of deformation. The amount of deformation necessary for continuous working and for annealed Pantal is about 50%. Hard rolled sheet pressure welds better than annealed; hence, a heat treatment can be saved in the manufacture of the sheet. The pressure weldability of various aluminum alloys follows in descending order: hard rolled aluminum-manganese sheets and pure hard rolled aluminum, Pantal, aluminum-zinc-magnesium alloys, Hydronalium (much inferior), Duralplat and duralumin (unsatisfactory), magnesium alloys (not pressure weldable).

After thorough cleaning of the surface the sheets must not be left more than 1 to 1.5 hr. before welding. The oft-recommended pickling in caustic soda without previous acid treatment or after alkaline degreasing is not sufficiently uniform. Brushing alone without pickling is likely to cause failures.

To prevent the article sticking to the die, a definite roughness of the welding tooth is required. The tooth is first ground and then thoroughly coated with a talc-saltpeter mixture before the first heating. Every second sheet must be thinly smeared with a 2:1 mixture of talc and saltpeter with water. The parts must be washed immediately after welding.

Requirements for tightness of cooler elements are severe. Rejects amount to 2 to 5% even with excellent sheet surfaces. If dirt is not the cause, it may be too much thickness which in turn is usually due to wrong temperatures or slow heating.

Because of the precisely machined dies required, the process is suitable only for mass-produced articles from sheet. It is best suited to hollow articles. Steel parts can be pressed with the light alloy and shrunk in. Fundamentally, the sheet thickness is unlimited. Work has been done up to 0.2 in. but the heating time increases greatly with increasing sheet thickness. ◆



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